HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF AN ENERGY ABSORBING BARRIER EMPLOYING SAND-FILLED FRANGIBLE PLASTIC BARRELS SERIES XXIV

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STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

...EARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636405-4

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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M&R 636405-4
Final Report
Sand-Filled Frangible
Plastic Barrels

July 1971

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report entitled:

DYNAMIC TESTS OF AN ENERGY ABSORBING BARRIER

EMPLOYING SAND-FILLED FRANGIBLE PLASTIC BARRELS

SERIES XXIV

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Under the General Direction of

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Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, E. F., Stoker, J. R., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Sand-Filled Frangible Plastic Barrels", State of California, Department of Public Works, Division of Highways, Materials and Research Department Research Report 636405-4.

ABSTRACT: The results of three full scale vehicle impact tests into energy absorbing barriers employing sand-filled frangible plastic barrels are reported. The barriers were designed for placement in front of fixed objects located in freeway gores.

The test barriers were composed of an array of 15 to 17 frangible plastic cylinders, 36 inches in diameter by 30 and 36 inches high, containing sand in amounts varying from 200 lbs. in the nose barrels to 2100 lbs. in the rearmost barrels. Except for the 2100 lb. barrels, which were filled with sand, all the barrels contained foam plastic cores to support the sand at or above the center of gravity of most passenger vehicles. The barriers were 21' and 25' long and tapered from a 3' width at the nose to a 9' width at the rear. Plastic lids were riveted on each barrel; the barrels were not attached to the ground.

Sedans weighing approximately 4700 lbs. impacted the nose of the barrier head-on and at a 15° angle. A small sedan weighing about 1900 lbs. impacted the nose of the barrier head-on. All vehicles had impact velocities slightly less than 60 mph. The driver dummy in each vehicle was restrained with a lap belt.

Recorded average longitudinal vehicular passenger compartment decelerations for the highest 50 millisecond period ranged from 7.9 to 10.7 G's. In general, these values were considered tolerable for lap-belted passengers and would have resulted in no more than moderate injuries in most cases. However, the computed Gadd Severity Index (from head decelerations) for the lap-belted dummy driver in the light sedan indicated "fatal" head injuries were incurred. Thus, even though collisions with the barrier will result in much lower deceleration values during vehicular impacts than would occur when striking a fixed object, the chance of serious injury is still dependent on the type of passenger restraint system used and the impact protection provided by the interior surfaces of the vehicular passenger compartment. Fully restrained occupants (lap belt and shoulder harness) would probably have sustained little or no injury.

The vehicles remained relatively stable during all three impacts. The 4700 lb. vehicles penetrated the barrier with low exit velocities after sustaining moderate damage. Most of the barrels in each test barrier were demolished during each impact.

The debris scatter in the lateral direction during the head-on impact was minimal except for the lids. The angle impact into the barrier nose caused considerable amounts of sand and broken barrels to be thrown into the "traveled way".

The barrier was also judged acceptable in the areas of cost, ease of construction and maintenance, aesthetics, simplicity and versatility, and is recommended for use in operational trial installations.

KEY WORDS: Barriers, dynamic tests, impact tests, attenuation, bumpers, cushioning, energy absorbers, kinematics, vehicle dynamics.

ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, as Item D-4-69 of Work Program HPR-1(5), Part 2, Research. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

The following staff members of the Materials and Research Department were instrumental in the completion of the tests reported herein:

Roger Pelkey Orvis Box Lee Staus Joe Eagan Dale Sathre	Construction of barrier, preparation and operation of test vehicle and other test equipment and assembly of the test data.
Bill Chow Merle Wilson Delmar Gans William Ng	Instrumentation of test vehicles and dummies.
Robert Mortensen	Data and documentary photography.
George Oki	Fabrication of Volkswagen tow system components.

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I. INTRODUCTION

General

During 1967 and 1968, approximately 25% of all the fatalities on the California freeway system were caused by vehicles running off the road and colliding with fixed objects such as bridge piers and large sign posts. Consequently, the California Division of Highways now strives to provide a 30 ft. wide recovery area alongside the traveled way clear of fixed objects. Whenever possible, those fixed objects that cannot be removed from this recovery area are made "breakaway". However, one problem that has defied effective solution has been that of gore areas of freeway off-ramps which contain large sign posts, bridge rail end posts, and other rigid structures. Various types of energy absorbing barriers have been proposed for installation in front of or around these fixed objects to cushion vehicular impacts. The California Division of Highways has conducted full scale crash tests of two of these types, namely, barriers incorporating water-filled plastic cells and barriers incorporating empty, 55 gallon steel oil drums[1,2]. Another proposed solution to this problem consists of placing an array of sand-filled frangible plastic barrels between the traveled way and the fixed object. Three tests of this type of barrier are reported herein.

Background

The object of the tests reported herein was to assess the effectiveness of a barrier developed by John Fitch and manufactured by Fibco, Incorporated, of Hartford, Connecticut. During 1967 Fitch conducted over thirty tests of his barrier in an attempt to develop an impact attenuator consisting of sand bags supported on various types of material at a height close to that of the center of gravity of a standard vehicle. Fitch himself drove the test vehicle during some of these tests at speeds of up to 60 mph. This series of tests was supported by a few interested firms and engineering assistance was provided by the New York State Department of Transportation. The tests proved the feasibility of using the concept of momentum transfer from the impacting vehicle to the sand, but the need for a more sophisticated system for containing the sand was evident. A weatherproof, cylindrical, plastic barrel was developed that would provide lateral support for the sand but would shatter relatively easily when struck by an impacting vehicle. The barrel material developed was a high density polyethylene that was produced using a structural foam process.

In April 1969 Fitch conducted another series of six tests. This phase of his testing was supported by the State of Connecticut under the aspices of a National Highway Safety Board project grant. The tests were conducted at speeds of 40-50 mph using vehicles weighing 1700, 3000, 3500, and 3900 lbs. The test barriers were 14'-6" to 25'-0" long. A live driver was used in two tests. The barrels were placed in an open area with no fixed object behind the barrier. In all the tests except those with a 1700 lb. car, the stopping distance exceeded the barrier length. Reports of the tests indicated that the test vehicles were decelerated in an effective, stable manner; however, there was no instrumentation to measure peak G's on the vehicle.

Subsequent to the above tests, Fitch barriers have been installed at locations in several states. A few collisions with these barriers have been recorded with generally favorable performance.

The sand inertial barrier concept appeared promising due to its apparent effectiveness in adequately decelerating impacting vehicles, adaptability to varied site conditions, simplicity, and relatively low first cost. Due to the limited number of formally documented tests that had been conducted, a series of 60 mph tests using instrumented, relatively heavy and light vehicles was deemed necessary to more accurately evaluate the barrier's effectiveness. Also of concern was the amount of debris that would be generated as the barrier decelerated an impacting vehicle. The three tests reported herein were therefore conducted to further evaluate this barrier.

II. OBJECTIVE

The objective of this research was to conduct instrumented vehicular impact tests of energy absorbing barriers incorporating sand-filled plastic containers and, based upon the results of these tests, determine the degree to which these barriers would minimize the hazards created by many existing gore separation structures and other fixed objects. The criteria itemized below were used to evaluate the barrier design:

1. The impact severity for the occupants of errant vehicles involved in head-on collisions into fixed objects located in gores must be reduced to a survivable level at impact velocities of 60 mph and less.

2. The barrier components should not be susceptible to dislodgement or ejection onto the traveled way when an impact occurs, such that they become a hazard to adjacent traffic.

3. First cost and maintenance costs should be economically feasible.

4. On-site repair time should be minimal because of the safety hazards to maintenance personnel and adjacent traffic when field repairs are in progress.

III. CONCLUSIONS

The results of the three full scale tests reported herein indicate that the hazards presented by many existing gore separation structures and other fixed objects can be significantly reduced by providing protection with energy absorbing barriers incorporating sand-filled plastic barrels.

The electronically measured vehicular and dummy decelerations, confirmed by analysis of the photographic data, indicated that occupants of full size vehicles (4700 lbs. including occupants) impacting these barriers at 60 mph will, in most cases, sustain little or no injury if wearing a lap belt and shoulder harness, minor injuries if wearing only a lap belt, and moderate injuries if unrestrained. However, occupants of smaller vehicles such as a 2000 lb. Volkswagen may sustain serious injuries, even if restrained by a lap belt. As this barrier will provide no significant vehicular redirection, the lateral decelerations sustained during collisions with the barrier will be minimal.

Confinement of the sand will result in a tendency for an impacting vehicle to rise. Thus, the modules placed near the rear of the barrier should not be full (eliminate the relatively ineffective lower foot of sand) and a two foot wide void should be provided between the rear of the barrier and the face of the fixed object to prevent accumulation of barrier debris and the associated formation of a ramp adjacent to the fixed object.

A considerable amount of debris will be generated during a 60 mph collision with this barrier. However, most of this debris will be propelled straight ahead of the impacting vehicle. Thus, this debris will present a hazard for adjacent motorists only when high speed, oblique angle impacts occur unless the debris is scattered by wind. Tieing the lids together and encasing the core material will improve this debris problem somewhat.

The reported first cost of approximately 20 installations of this barrier in Connecticut ranged from $1500 to $3300 each[3]. Each barrel used for the <u>test</u> barriers cost $130. Thus, the material cost for the test barriers was approximately $2000 as the test barriers contained 15 and 17 modules each. Although little or no routine maintenance should be required, even relatively mild impacts will almost always require replacement of at least several barrels. However, the simplicity of the barrier's construction will permit minimal on-site repair time after the debris removal operations are complete.

IV. TEST PROCEDURE

Test Site

All three tests were conducted on a section of runway at the Lincoln Municipal Airport located near Lincoln, California.

Test Vehicles

The full size vehicles used were 1968 Dodge sedans. Including dummies and instrumentation, the vehicles weighed approximately 4700 lbs. Control of the vehicles along the impact course was accomplished by a remote operator following 200 feet behind the test vehicle in a control car equipped with a tone transmission system. A trip line in the path of the test car was used to cut off its ignition 10 feet prior to impact. The brakes were not applied before or during impact. A more complete description of the remote control equipment is contained in Reference 4.

A 1961 Volkswagen was used for one of the tests. It was steered and braked by remote control from a follow car as in the other two tests; however, it was incapable of accelerating to 60 mph under its own power within the confines of the test site. Therefore, a cable tow system was devised to pull the VW into the barrier. The cable was extended from the VW to two ground mounted pulleys near the barrier, back to a pulley attached to the rear of a tow car going in the opposite direction, then to a deadman anchor near the other two ground mounted pulleys. This reverse tow system provided a mechanical advantage of two. Trip wires were rigged to release the cable from the VW a few feet in front of the barrier. A more complete description and some photographs of this system are included as Appendix A.

Test Dummy

One anthropometric dummy was placed in the driver's position. This 165 lb. dummy, representing a 50th percentile male, was restrained with a conventional lap belt. Another, larger anthropometric dummy weighing 210 lbs. and representing a 95th percentile male was placed on the passenger side of the front seat for one of the tests. See Plate 1, page 8, for the location and description of the instrumentation on the dummies.

Photographic Coverage

All the tests were recorded with high speed (250-400 frames per second) Photosonic motor-driven cameras which were manually actuated from a central control console. These cameras were located on the ground on both sides of the barrier and on a 30 ft. high light standard directly above the barrier. Ground cameras included closeup views and over-all views. Scotchcal tape "butterfly" targets on the side of the vehicle were used for data reduction of the movies with a Vanguard Motion Analyzer.

Another Photosonic camera was located in the rear of the vehicle to film the movement of the dummy; floodlights were placed within the vehicle passenger compartment for illumination. This camera was started by means of a pin actuated switch on the rear bumper of the test vehicle after the test vehicle had traveled approximately 50 feet toward the barrier.

A motor driven Hulcher camera with a speed of approximately 20 frames per second was located on scaffolding and provided documentary coverage of the tests. A ground mounted high-speed camera and a normal-speed camera were hand panned through impact. Still photos, slides, and documentary movies were taken of the test barrier and vehicle.

Some of the Photosonic cameras were provided with a 1000 cycle per second timing light generator that impressed red-orange pips on the edge of the film. These pips were then counted on the Motion Analyzer to determine the exact frame rates of the cameras.

Five tape switches were placed at precise ten foot intervals on the vehicle path forward of the point of impact and were actuated by the approaching test vehicle. The last tape switch was placed so that the vehicle passed over it coincident with initial impact of the barrier. Tire contact with each tape switch triggered one of a series of five flashbulbs located in view of most of the data cameras. These flashbulbs provided event correlation between all stationary cameras; they were also used to compute impact velocity of the vehicle using the film analyzer.

Flashbulbs mounted on the rear fenders of the test vehicle were installed to establish vehicle location and the time at which the brakes were applied if this became necessary. They also served to alert the control car driver that the test car's brakes had been applied. These flashbulbs were fired when the brake actuating relay was pulsed by the remote operator or if the remote radio equipment failed.

Data Acquisition and Processing

Four accelerometers were mounted on the driver dummy, four accelerometers were mounted on the vehicle, and one seat belt transducer was used on the driver dummy's lap belt. See Plate 1, page 8, for the location and description of this instrumentation. Transducer information was transmitted from the crash vehicle to a 14 channel Hewlett Packard 3924 magnetic tape system through two Belden #8728 cables in Test 241 and one Belden #8776 umbilical cable in Tests 242 and 243. The signals from three strain gages on the bridge approach guardrail were also transmitted by cable to the tape recorder for Test 241 (Plate 2, page 9). The Statham accelerometers used were all of the unbonded linear strain gage type.

Tapeswitches were located in the vehicle path at a distance of 2'-6" (to record the approximate time of impact) and 22'-6" in front of the point of impact on the barrier nose. The front and rear wheels of the vehicle activated these switches. This caused an "event marker" signal to be recorded along with the accelerometer data on the tape recorder. A third air hose type switch was mounted along the front of the bumper of the vehicle to record the time of impact. Concurrently, a 100 millisecond time cycle was recorded on the tape recorder.

After the test, the data on the tape was played back through a Visicorder which produced an oscillographic trace (line) on paper. Each paper record contained an accelerometer data trace, the front and rear wheel event marker trace, and the 100 millisecond time cycle trace (see Appendix E).

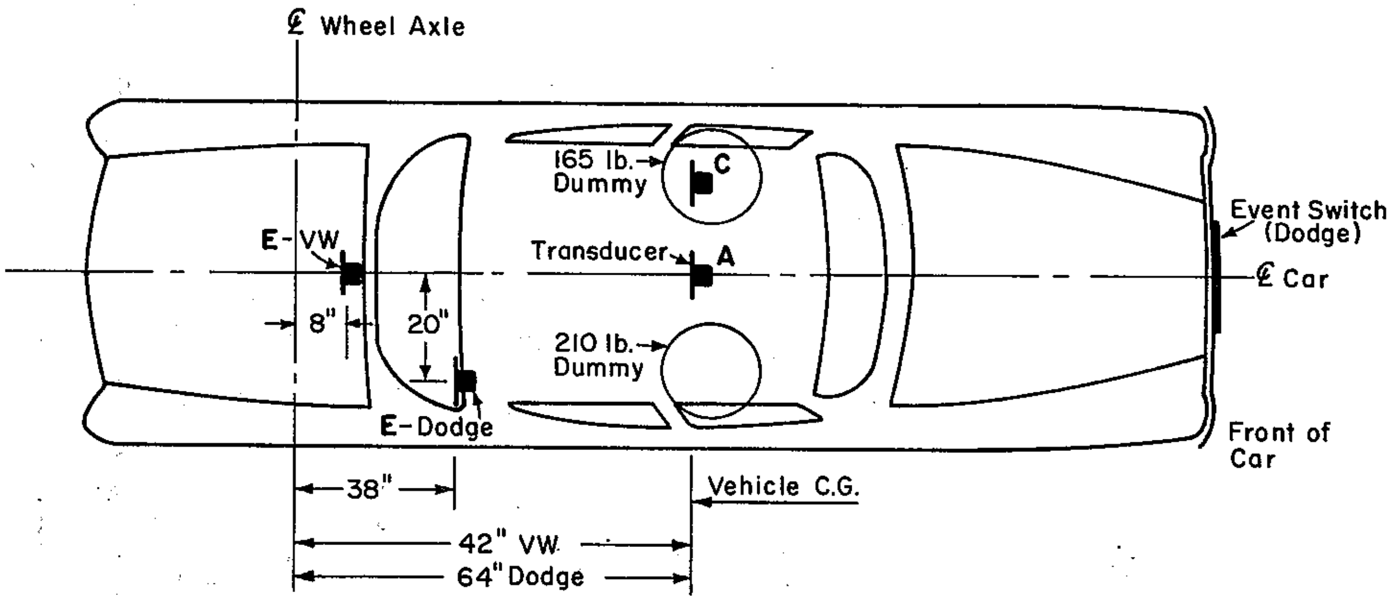
For Test 241, the tape recorder playback was reduced from the recording speed by a ratio of 8 to 1. Theoretically, this produced an "unfiltered" trace with a frequency response of 8 times 270 or 2160 Hertz subject to the limitations of the accelerometers and the rest of the recording system. A "filtered" trace was also obtained from the Visicorder using the tape recorder playback speed reduction of 8 to 1 and a Krohn-Hite filter for an effective filtration rate of 100 Hertz. This filtering is an integration process which removes the high frequency spikes of acceleration and produces a smoothed out curve. The filtered traces were easier to compare and to use for data reduction than the unfiltered traces. They also gave a better over-all record of the motion of the dummy and vehicle. The high frequency spikes on the unfiltered records were assumed to be relatively insignificant as related to the over-all motion of the vehicle.

After the data from Test 241 had been filtered, there was a malfunction of the Krohn-Hite filter so the method of Visicorder playback was changed to process data from Tests 242 and 243. The magnetic tape playback speed reduction was kept at an 8 to 1 ratio but a Brush orange dot galvanometer with a frequency response of 100 Hertz was used to obtain an "unfiltered" record of the impact signal resulting in an effective response of 800 Hertz. A Brush brown dot galvanometer with a frequency response of 22 Hertz was then used to obtain an effective response of 176 Hertz on the "filtered" records. However, this vehicular deceleration data filtered at 176 Hertz in Tests 242 and 243 proved to be too unwieldly for numerical work so a "hand filtered" line was superimposed on it. This eliminated the high frequency spikes and permitted the computation of the maximum deceleration values given in the test results. Copies of the filtered records of impact data for all the tests are contained in Appendix E.

Plate 1

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION



Tests 241 & 243
(Dodge)

CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	C	Longitudinal accelerometer - head.
2	C	Lateral accelerometer - head.
3	C	Vertical accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	A	Lateral accelerometer.
7	E	Longitudinal accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.
13	L	Event switch mounted across front bumper.
	E	Impact-O-Graph with mechanical stylus.

Test 242
(Volkswagen)

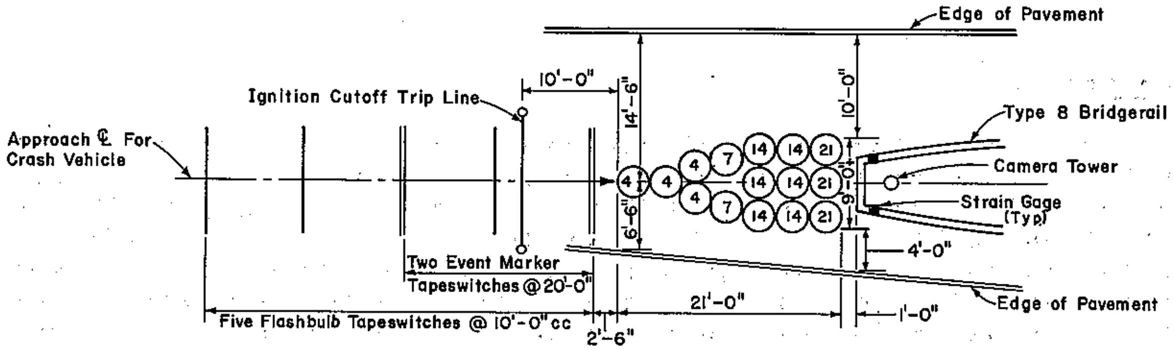
1	C	Longitudinal accelerometer - head.
2	C	Vertical accelerometer - head.
3	C	Lateral accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	E	Longitudinal accelerometer.
7	A	Lateral accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.

Note:

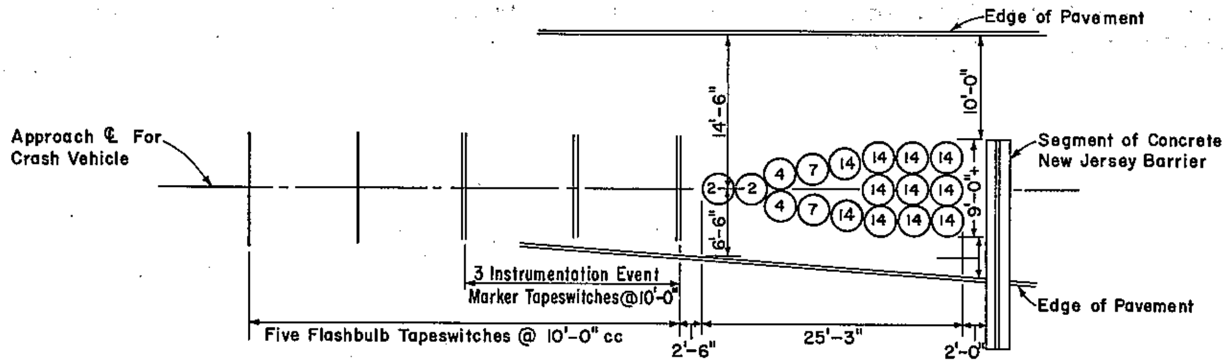
[1] A and E on vehicle floor; C on back of dummy's chest cavity and back of dummy's head cavity.

PLATE 2

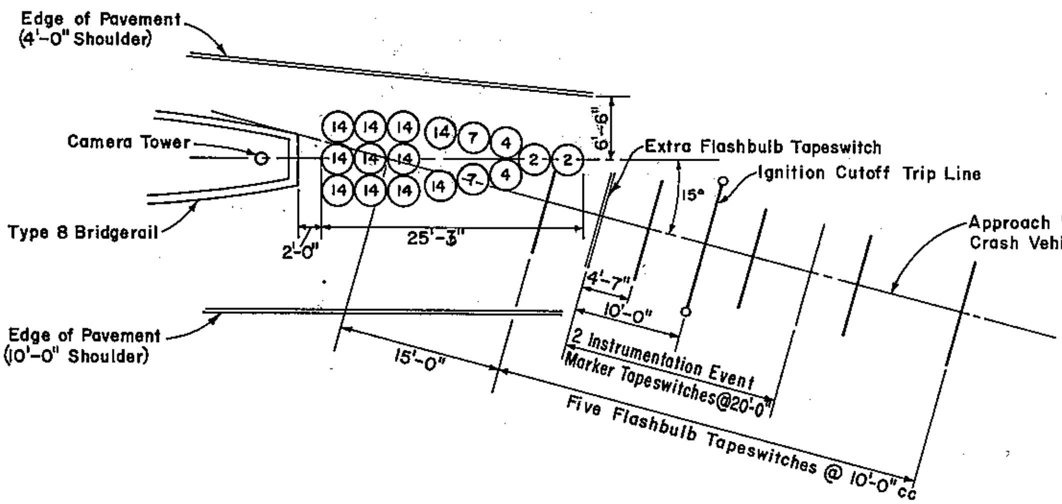
BARRIER INSTRUMENTATION



TEST 241



TEST 242



TEST 243

LEGEND

■ - Strain gage on top surface of upper and lower rails, 8 in. behind nose of bridgerail - total 3

(14) - Barrels with nominal wt. of sand in hundreds of pounds.

V. DESCRIPTION OF TEST BARRIER

Introduction

The test barrier for Test 241 was composed of an array of frangible plastic barrels containing varied amounts of sand and was placed in front of a California Type 8 Bridge Approach Guardrail (BAGR - see Figure 1 and Exhibits 1 and 2). Deceleration of the impacting vehicle was obtained through a transfer of momentum from the vehicle to the sand. The foamed plastic used for the barrels was frangible so the sand was relatively unconfined when the modules were subjected to an impact-type load. Thus the barrier design was based on the conservation of momentum with adjustments so that standard barrel sizes could be used. The over-all barrier length for the first test was 21'±. An additional 1' gap was left between the rear of the barrier and the nose of the BAGR to provide some additional deceleration distance and to minimize the accumulation of sand against the BAGR which would provide a ramp for the vehicle.

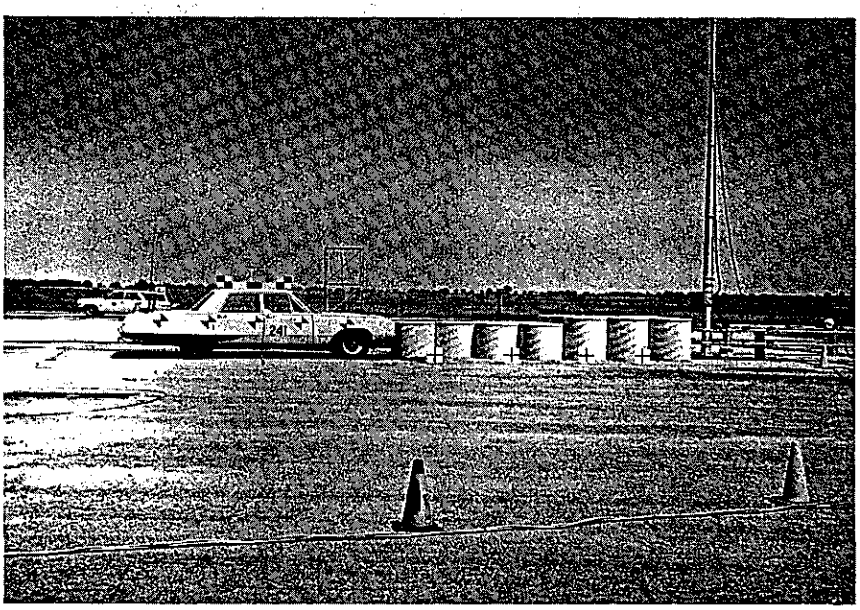
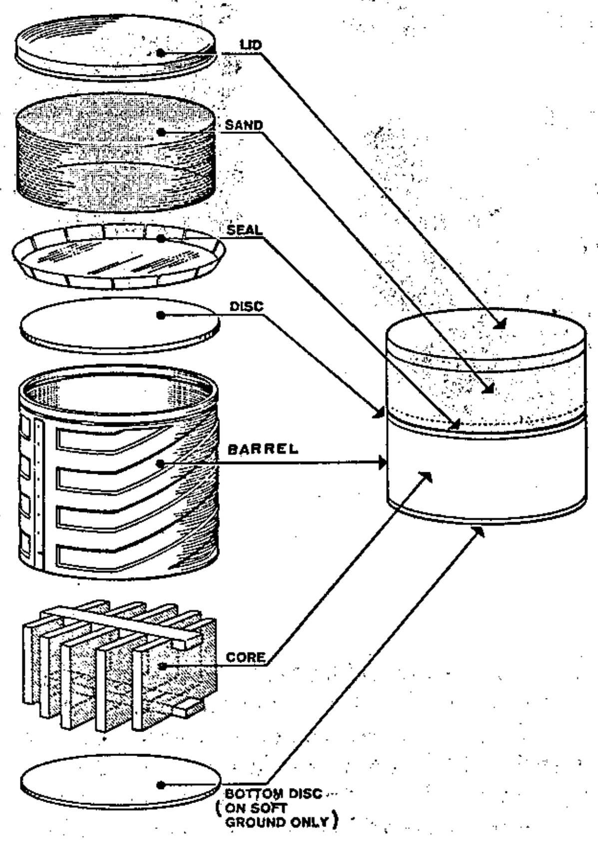


FIGURE 1

Barrier Module

Several components were used to construct each barrel (Figure 2). Frangible, high density polyethylene plastic was used as the barrel material and a thin flexible plastic was used for the lids. A round plastic disc was available to place at the bottom of the barrel on soft ground; however, it was unnecessary for the test barrier. An interlocking group of seven polystyrene (plastic) boards served as a core to support the sand at the proper height in the barrel. Covering the core was a thin, hard, circular, high impact polystyrene (plastic) disc. A flexible clear plastic circular seal with upturned edges was seated on top of the disc to prevent the sand from spilling down to the ground. The sand was poured into the barrel to obtain the desired weight and then a lid was riveted to the barrel in three or four places. Core heights available from the manufacturer permitted nominal sand weights (based on a sand density of 100 pcf) of 200, 400, 700, and 1400 lbs.; a full barrel (with no core) contained 2100 lbs. of sand. The barrels holding 1400 and 2100 lbs. of sand were 3' in diameter and 3' high; all other barrels were 3' diameter and 2'-6" high.



BARREL COMPONENTS

FIGURE 2

Barrier Design

The barrier was constructed using barrels containing 400 lbs. of sand at the nose and 2100 lb. barrels at the rear (see Exhibit I and Figures 3 and 4). This mass gradation was designed to obtain a relatively uniform rate of deceleration during impacts. The barrier had a width of 3' (one barrel) at the nose and was tapered out to a width of 9' (three barrels) at the rear.

FIGURE 3

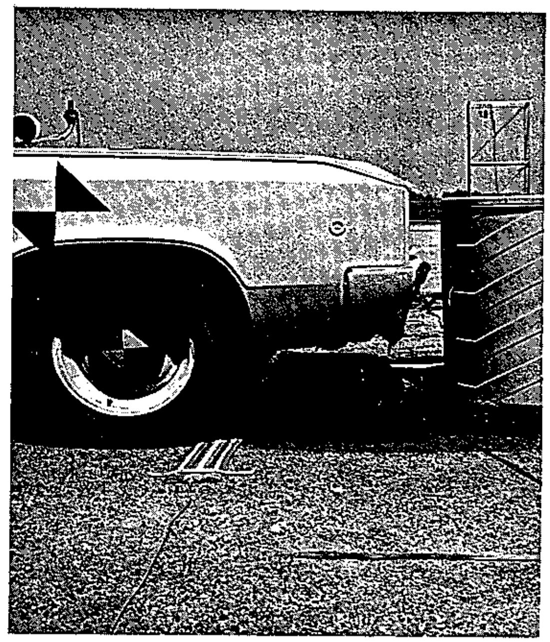


FIGURE 4

Simulated shoulder lines were placed 10 ft. off the left side of the barrier and four feet off the right side as measured at the last row of barrels. These dimensions represented a four lane freeway with a two lane off ramp as per the California Division of Highways' Planning Manual. The simulated gore area was 23' wide at this point. See Appendix B and Appendix C for instructions on installing the barrier and for notes on the assembly of the test barriers.

VI. TEST RESULTS

Test 241

Test Vehicle

A 1968 Dodge sedan weighing 4690 pounds was used as the test vehicle. The 4690 pounds included the 165 pound dummy placed in the driver's seat and the 210 pound dummy placed on the passenger side of the front seat. Both dummies were restrained with lap belts. The left front door and the gas tank were both removed prior to the test.

Vehicle Behavior and Damage

See Plate 3, page 16, for a summary of the test results. The vehicle, traveling 58 mph, impacted the barrier head-on about one foot to the left of the nose and plowed through the entire barrier (Figures 5 and 6). About 3-4 feet in front of the bridge railing, it ramped up on barrier debris and came to rest on the bridge rail just in front of the camera tower, 24' behind the nose of the barrier. As it ramped up, it tilted sharply in a counterclockwise direction, since the left front wheel was off the bridge rail, and almost turned over (Figure 7) before returning to its final position. The left rear fender was flush with the ground when the vehicle came to rest.

FIGURE 5

FIGURE 6

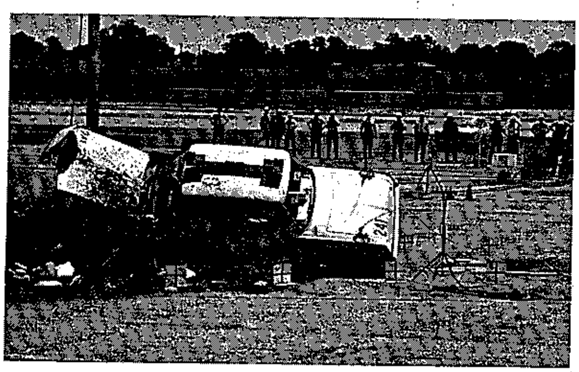


FIGURE 7

Damage was confined mainly to the front end. Maximum significant crush at the center of the vehicle forestructure was 1'-8". The crush was fairly uniform across the front of the vehicle but slightly less on the left side (see Figure 8 and Exhibit 3). The lower frame member, bumper, and front fenders were all severely buckled and the radiator was shoved back against the engine. On the passenger side, the front windshield was cracked where the sun visor came down and was struck by the dummy's head. No crimp in the roof over the doorpost was observed. The doorpost on the driver's side was torn loose from its roof connection and displaced back ½". Immediately after impact, the hood flew open. However, it sustained no damage, mainly because the level of the hood was higher than the 2'-6" high barrels at the nose of the barrier.

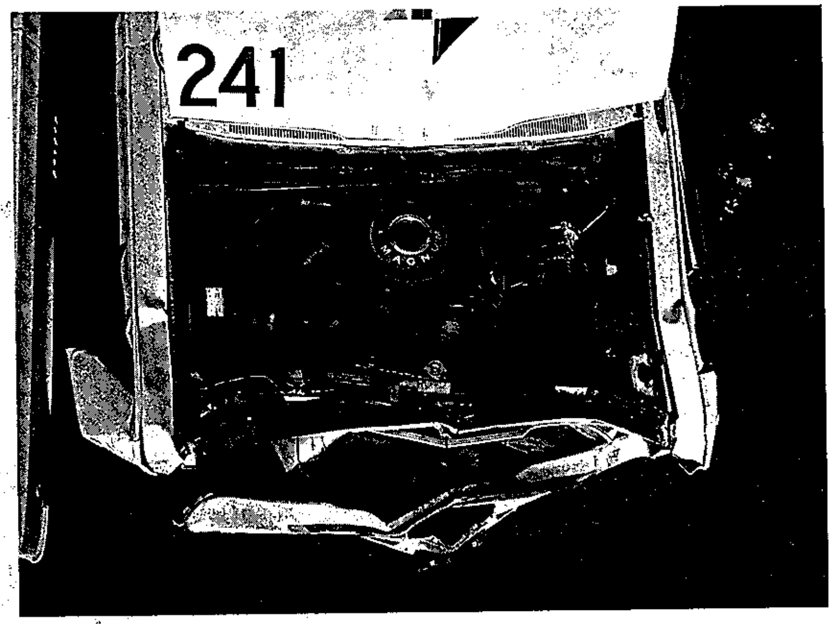


FIGURE 8

Barrier Damage

Most of the broken foam plastic core pieces stayed under the vehicle. No lids were broken. However, all the lids were detached from the barrels and several were displaced a considerable distance. Broken barrel fragments did not travel far; four barrels along the right side of the barrier were mostly intact. They had been shoved sideways and tipped over, spilling sand out rather than "exploding". It appeared that most of the barrier resistance came from the left two-thirds of the barrier. Other than lids, little debris flew outside the "edge of pavement" lines except for some sand which extended 4-6 feet into traffic lanes on each side, beside the original barrier location on the right side and 10-15 feet beyond it on the left side (see Plate 4, page 17). The last one or two rows of barrels did not shatter but leaned and compressed against the bridge rail and then fractured. These barrel pieces, plus the sand which was intermixed, piled up in front of the bridge rail and provided a ramp for the car to climb up on the bridge rail. The broken plastic core pieces were small and mixed into the sand; hence, the sand did not appear suitable for reuse without sifting. Most of these fragments remained in the debris under the vehicle; however, many pieces on top of the pile, being light, were scattered quickly as the wind blew. This condition could pose a psychological hazard to drivers on an adjacent traveled way as they tried to dodge the pieces and widespread litter near the gore area.

Dummy Behavior

No damage to the dummies was observed; however, the dummy on the passenger side struck his head on the sun visor which in turn cracked the windshield. Steering wheel deformation was 2½"; the steering column collapsed 0.7".

Instrumentation Results

The accelerometer records were cut off about 200 milliseconds after impact on some of the channels when equipment in the test vehicle broke loose. It appeared, however, that in most cases the main pulse of the deceleration was recorded before the interruption. Using Visicorder traces filtered at 100 Hertz, the maximum average values of deceleration were as follows:

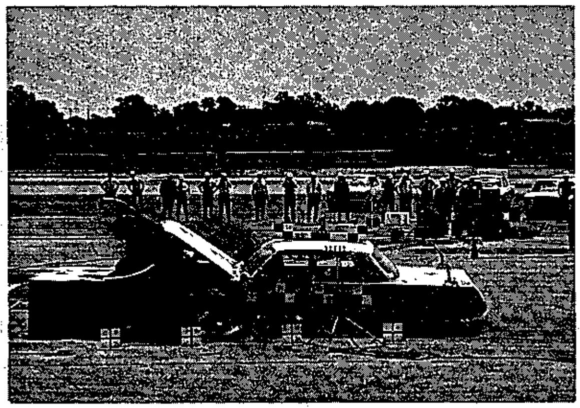
1.	Vehicle - longitudinal - highest 50 ms avg. (1 accelerometer - Location E)	10.7 G's
2.	Dummy driver - head - highest 50 ms avg. (resultant of long. and vert. accelerometers)	25.2 G's

A maximum lap belt load of 990 lbs. was recorded with the seat belt force transducer. Thus, the total load on the dummy was well below the 5000 lb. maximum permitted by federal standards[5]. The tubular steel bridge approach guardrails sustained stresses of 3240, 3620, and 6120 psi -- not excessive values. The highest 40 ms average vehicular longitudinal deceleration was 11.7 G's, just under the maximum value of 12 G's recommended by the Federal Highway Administration[6]. Records from the longitudinal and lateral accelerometers placed at the center of gravity of the vehicle (Location A) were cut off just before the main peak about 200 ms after impact.

The Gadd Severity Index was computed using longitudinal and vertical deceleration components of motion from accelerometers in the head of the dummy. For the highest 50 ms, the number was computed to be 185. This is well below the critical value of 1000. (See Part VII, Discussion, for an analysis of this instrumentation data; see Appendix E for the accelerometer and Impact-O-Graph records and graphs of the vehicular motion based on the film data).

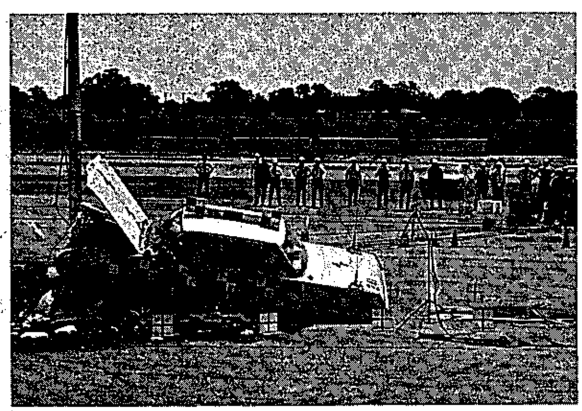
Plate 3

Impact + 0.027 Sec.



Impact + 0.231 Sec.

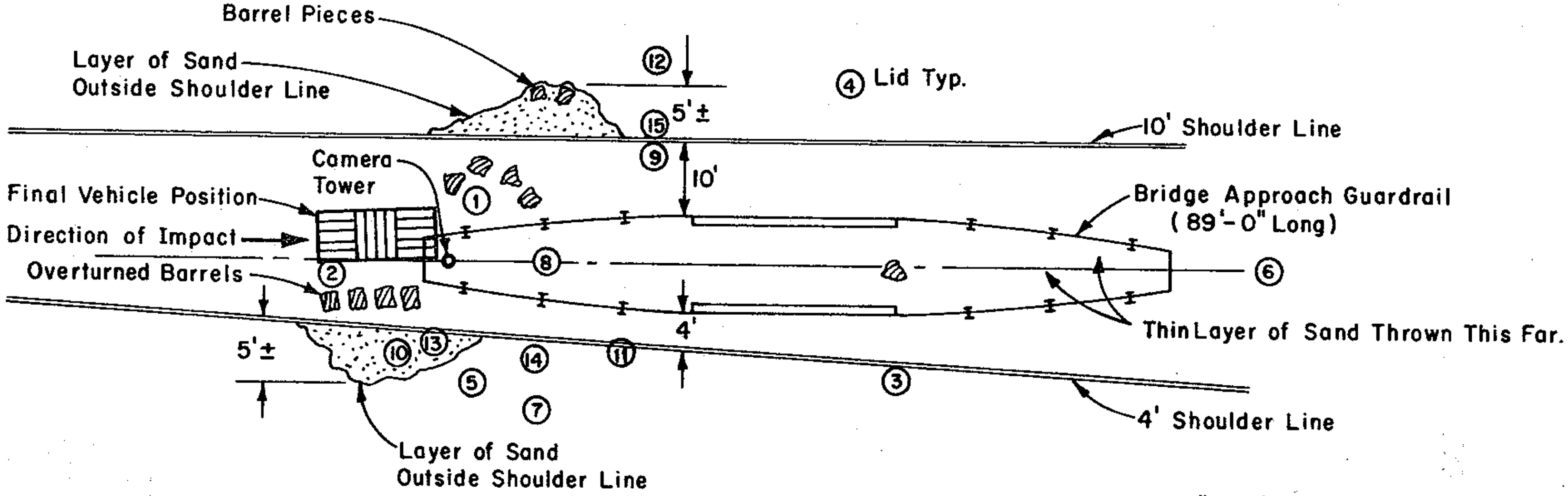
Impact + 0.435 Sec.



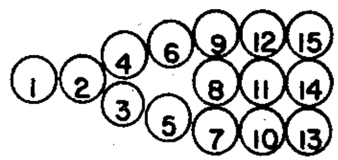
Impact + 2.373 Sec.

Test No.	241
Date of Test	May 21, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummies and instrumentation)	4690 lb.
Impact Velocity (V_o)	58.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap Belt
Barrier Depth	21'-10"
No. of Plastic Barrels	15

Deceleration Distance of Passenger Compartment	24'-0"
Maximum Vehicular Deformation at Forestructure	1'-8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 100 Hertz	10.7 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 24.0' (stopping distance)	4.7 G's
Gadd Severity Index (Dummy's head)	185



SCALE: 1" = 20'



ORIGINAL BARREL CONFIGURATION & NUMBERS

DEBRIS LOCATION DIAGRAM
TEST 241

Test 242

Barrier Description

The test barrier consisted of 17 plastic barrels filled with varied amounts of sand ranging from 200 lbs. at the nose of the barrier to 1400 lbs. at the rear (see Exhibit 1 and Figures 9 and 10). The black tape on the barrels shows the bottom level of sand in the barrels, or top and bottom levels in the front barrels. The above weights are nominal for an assumed sand density of 100 pcf. Since it was determined that the actual (moist) sand density for Test 241 was only 80 pcf, sand that had been run through a dryer just prior to delivery was used for Test 242. This sand had a higher density of 88 pcf at a moisture content of 0.4%. The plastic barrel components were all identical to those used for Test 241.

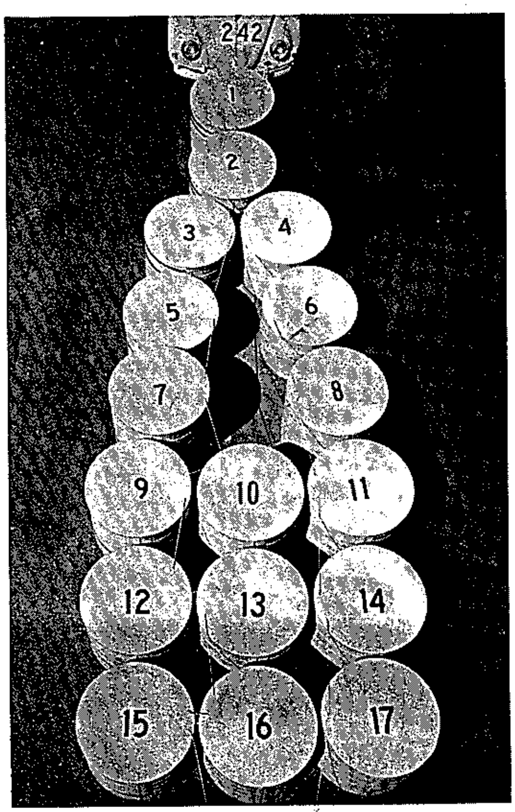


FIGURE 9

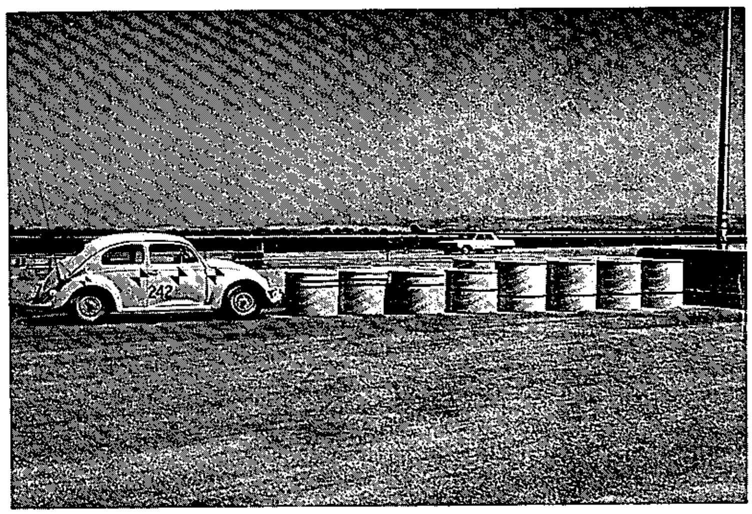


FIGURE 10

The barrier was lengthened from 21' (Test 241) to 24' (nominal) and the barrel weights were decreased at the nose to provide a softer impact. Also, the rear barrels were changed from 2100 lbs. to 1400 lbs. and the void space at the rear increased from 1' to 2' in an attempt to lessen the buildup of sand and debris against the fixed object which had caused ramping in Test 241. A section of New Jersey concrete median barrier was used as the fixed object instead of the bridge rail because of the location of the ground anchors for the cable tow system used in this test.

Cotton sash cord was threaded through two small holes in the lid of each barrel. The cord was continuous through all 17 lids and was tied to the camera tower to prevent the lids from sailing onto the traveled way after impact as had occurred during Test 241.

Test Vehicle

A 1940 lb. 1957 Volkswagen sedan was used for the test vehicle. The 1940 lb. weight included a 165 lb. dummy which was restrained in the driver's seat with a lap belt, the gas tank filled with water, the spare tire (in front), and all the equipment used for radio control. The left door was replaced with a small steel channel brace so the action of the dummy could be recorded by the cameras. See Appendix A for a description of the tow system used to pull the VW.

Vehicle Behavior and Damage

See Plate 5, page 22, for a summary of the test results. The VW hit the barrier nose head-on about 9" to the left of the barrier center line at an impact velocity of 59 mph. The vehicle came to rest 19' beyond the nose of the barrier with all its wheels on the ground (Figures 11 and 12). During impact there was a 1'-4" rise at the rear of the vehicle (measured at a target on the right rear fender).

FIGURE 11

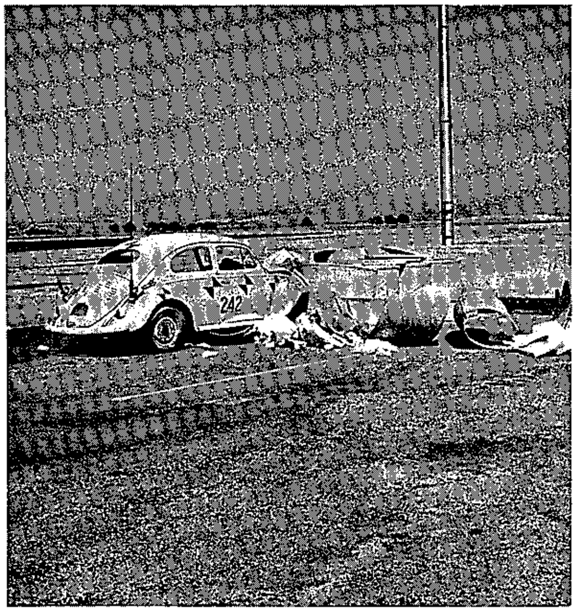


FIGURE 12

The front trunk lid remained closed and was moderately buckled, as were the front fenders. Maximum crush at the forestructure was only 8" (see Exhibit 3 and Figure 13). The entire windshield popped out due to the impact from the dummy's head.

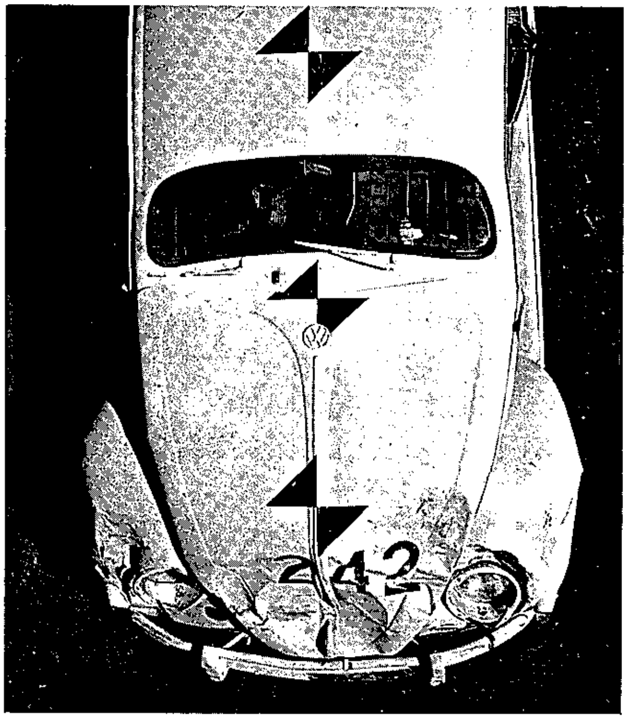


FIGURE 13

Barrier Damage

Plate 6, page 23, shows the location of the barrier debris. A small number of barrel core pieces were under the VW but there was no other debris under or behind it. There was no debris outside the 10' shoulder line but a small amount extended 9' beyond the 4' shoulder line. There was no sand covering the front of the VW. Very little debris was found beyond the back of the barrier. The lids all remained attached to the cotton rope and were clustered near the rear of the barrier. At least nine of the barrels were totally destroyed; four or five barrels were compressed but unbroken so they could have been reused; however, some of their inner foam plastic cores were crushed; three barrels were undamaged and undisturbed. The compressed barrels had moved forward during impact; it is unknown whether they could have been dragged on the ground and repositioned without breaking the plastic barrels and cores or spilling the sand.

Dummy Behavior

The dummy's forehead, moderately scuffed where it hit the windshield, was covered with small particles of imbedded glass. In addition to forcing out the windshield, the dummy's head left a small dent in the relatively stiff dashboard. There was no steering wheel in place due to the remote steering apparatus; hence, no steering wheel deformation measurement could be taken. The substitution of a small pulley for the standard VW steering wheel may have contributed to the excessive forward motion of the dummy.

Instrumentation Results

The highest average values of deceleration, based on filtered Visicorder traces, were as follows:

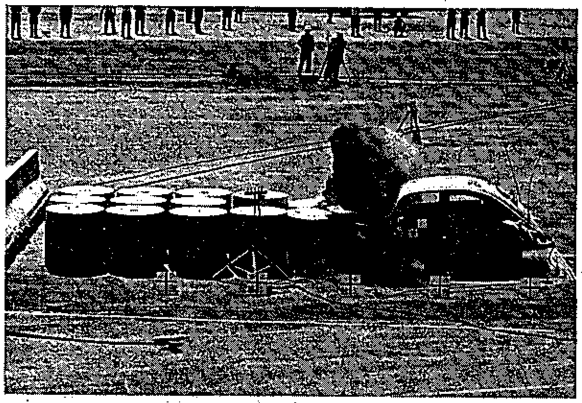
1.	Vehicle - longitudinal - highest 50 ms avg. (2 accelerometers)	8.7 G's
2.	Dummy driver - head - highest 50 ms avg. (resultant of long., lat., and vert. accelerometers at the same times after impact)	44.0 G's

Vehicular lateral decelerations (2 accelerometers) were about 2 G's maximum for 5 ms with one ms ringing spikes of 8-10 G's. The seat belt force transducer was inoperable. The Gadd Severity Index was computed to be 1280, significantly greater than the critical value of 1000.

See Appendix E for accelerometer and Impact-O-Graph records and graphs of vehicular motion based on film data. See Section VII, Discussion, for a discussion of the instrumentation results.

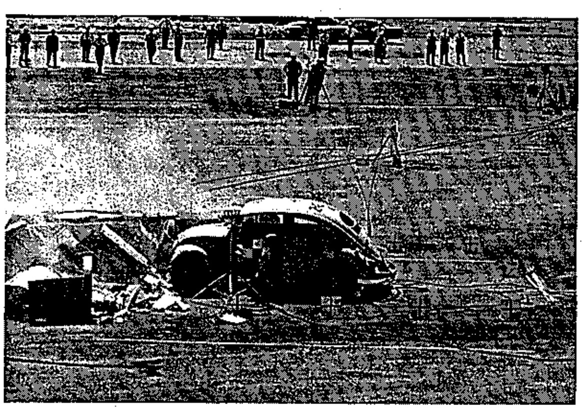
Plate 5

Impact + 0.022 Sec.



Impact + 0.163 Sec.

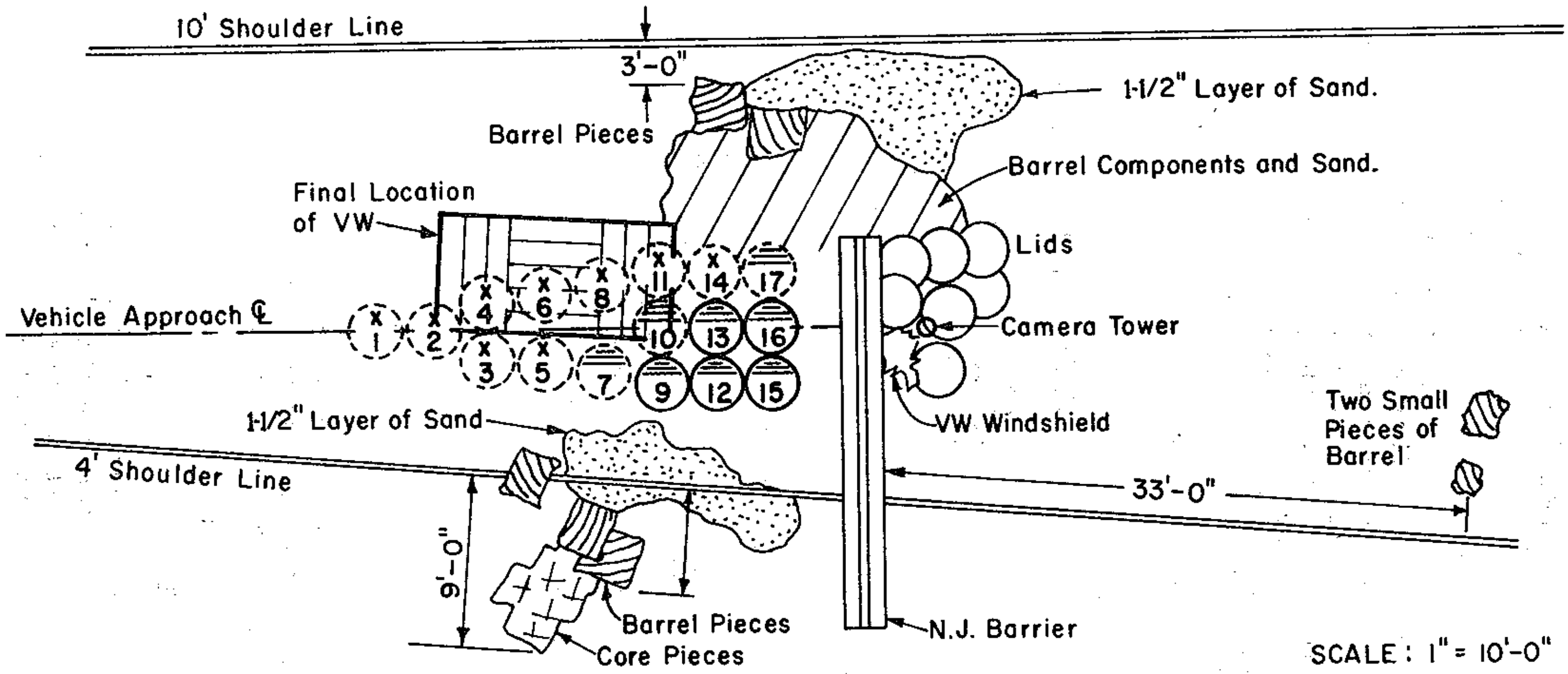
Impact + 0.586 Sec.



Impact + 4.536 Sec.

Test No.	242
Date of Test	September 4, 1970
Vehicle	1957 Volkswagen Sedan
Vehicle Weight (w/dummy & Instrumentation)	1940 lbs.
Impact Velocity (V_o)	59.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17

Deceleration Distance - Passenger Compartment	19'-0"
Maximum Vehicular Deformation at Forestructure	8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - Accelerometer Record, 176 Hertz	8.7 G's
Vehicular Deceleration = Avg. value based on $V_o^2 = 2as$ where s = 19.0' (stopping distance)	6.1 G's
Gadd Severity Index (Dummy's head)	1280



NOTES:

1. Barrels 9, 12, 13, 15, & 16 were all intact with lids on; two were slightly compressed. No. 16 was 9" from N.J. Barrier.
2. Barrels with an (X) were broken and thrown out of position.
3. All lids remained tied together.
4. Small number of core pieces under car.
5. All 4 wheels of VW on ground.
6. Barrels 7 & 10 were compressed but unbroken, lids were off.
7. Barrel 17 was compressed, unbroken, lid off, leaning against N.J. Barrier.

DEBRIS LOCATION DIAGRAM
TEST 242

Test 243

Barrier Description

The test barrier had the same size, number, and configuration of barrels as was used for Test 242 (Figures 14-16). As in Test 242, the sand was dried prior to delivery and had a density of 89.2 pcf at a moisture content of 0.8%.

Lids were attached to the barrels with four equidistant pop-rivets according to the manufacturer's directions. Three extra rivets were added in a short row next to one of these four rivets. This row of rivets was randomly located and was not on the same side of all the barrels. It was hoped that these extra rivets would provide a hinge effect and minimize the wide scattering of lids that occurred during Test 241.

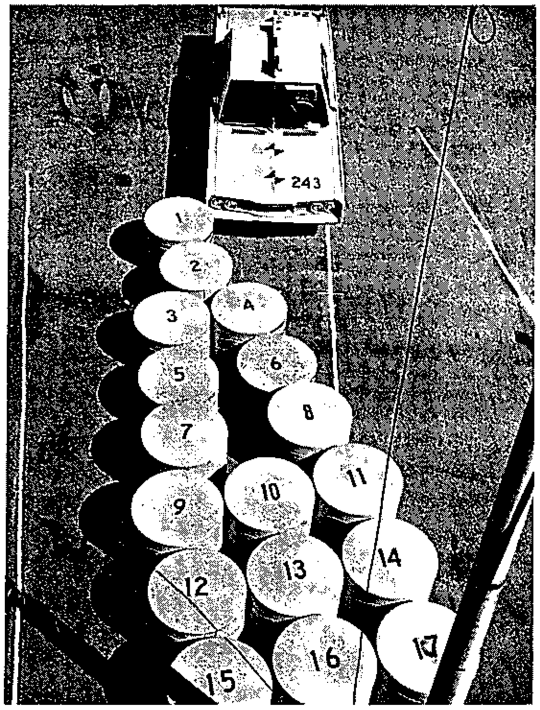


FIGURE 14

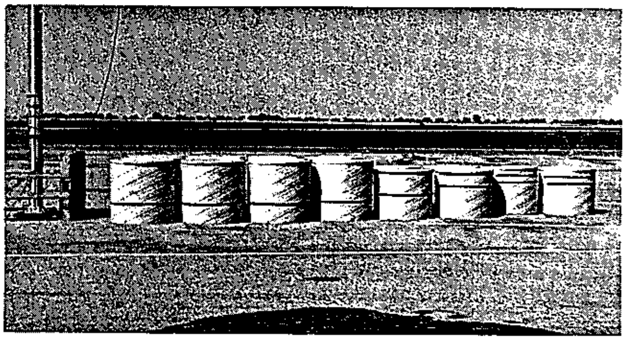


FIGURE 15

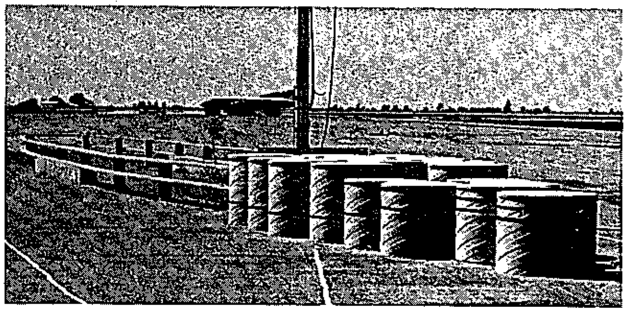


FIGURE 16

Test Vehicle

A 4770 lb. 1968 Dodge sedan was used as the test vehicle. The vehicle weight included a 165 lb. dummy restrained in the driver's seat with a lap belt, the water-filled gas tank, and all the radio control equipment.

Vehicle Behavior and Damage

See Plate 7, page 27, for a summary of the test results. The crash vehicle hit the nose of the barrier about a foot to the right of the planned point of impact at a speed of 57 mph and angle of 15^{o} with the barrier axis. It ramped up midway into the barrier and continued on over and through it, narrowly passed by the right corner of the Type 8 bridge approach guardrail nose, and stopped with the rear of the vehicle even with the last row of barrels in the barrier. It came to rest with all wheels on the ground on a thin layer of sand (Figures 17 and 18).

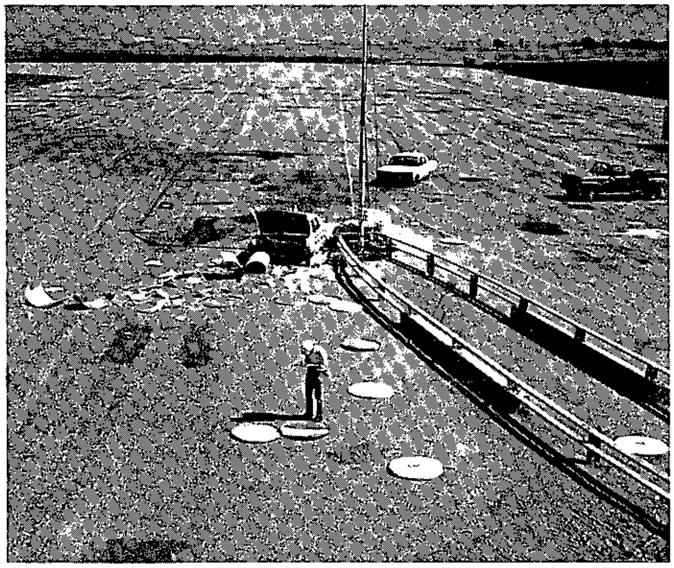


FIGURE 17

FIGURE 18

Damage to the vehicle forestructure was quite severe (Figure 19). The front end, including fenders, was uniformly crushed back against the engine. The maximum crush was 1'-9" (Exhibit 3). The engine was not displaced. The lower longitudinal front frame members and the bumper were sharply buckled down to the ground and back against the front wheels. The hood was undamaged due to the relatively low 30" height of the first four rows of barrels. A crimp in the roof was observed on the driver's side above the door-post. The rest of the car including the windshield, was undamaged.

FIGURE 19

Barrier Damage

Four barrels remained standing at the rear corner of the barrier. Of these, only two were undamaged. Large amounts of debris were scattered to the front and right front of the crash vehicle, some of which extended about 20' to the right of the 4' shoulder line and across the traffic lane (see Plate 8, page 28). The right front corner of the vehicle projected about 3' into the traffic lane; the right rear was about 1' inside the shoulder line.

The barrel lids were thrown far ahead of the vehicle, as much as 67-70 feet beyond the back of the barrier; however, only 3-4 lids landed in the traffic lanes. One landed 26' to the left of the 10' shoulder line. The extra rivets on the lids did not appear to have any beneficial effect. This may have been due, in part, to the lack of a washer on the rivet inside the barrel, a physically impossible condition. Therefore, the rivets had negligible resistance to the pullout forces generated by the impact.

A large collection of broken foam core pieces were found under the crash vehicle and many other pieces were thrown beyond the vehicle. These latter pieces were immediately blown freely about by a moderate wind and could have posed a psychological hazard had they been blowing across traffic lanes.

Dummy Behavior

There were no marks on the head of the dummy. The steering wheel was deformed on its lower side about 2-3/4" maximum out of its original plane. The collapsible steering column was jammed in 0.75".

Instrumentation Results

The highest average values of deceleration were as follows:

1. Vehicle - longitudinal-highest 50 ms avg. 7.9 G's

2. Dummy driver - head - highest 50 ms avg.
   (resultant of long., lat., and vert. accelerometers) 34 G's

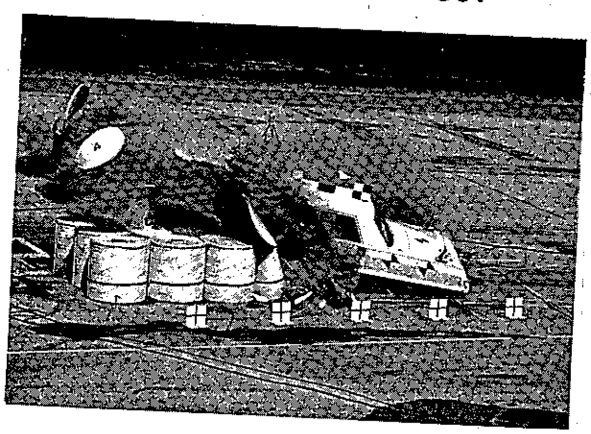
The seat belt force transducer had a maximum reading of 600 lbs. Vehicular lateral decelerations (2 accelerometers) were about 3 G's max. for 5 ms with 1 ms spikes up to 10 G's. The Gadd Severity Index was 580.

See Appendix E for accelerometer and Impact-O-Graph records and graphs of vehicular motion based on film data. See Section VII, Discussion, for additional comments on these instrumentation results.

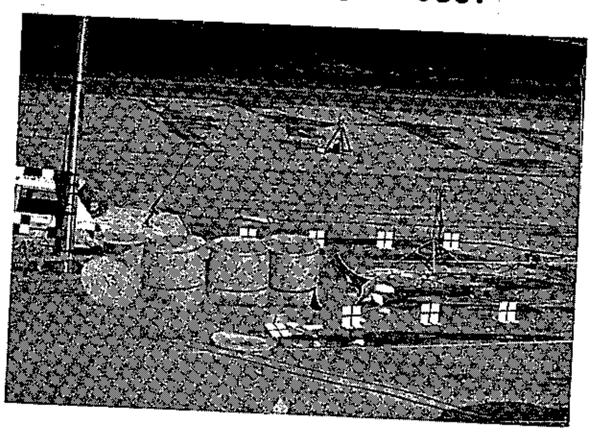
Plate 7

Impact + 0.012 Sec.

Impact + 0.180 Sec.



Impact + 0.348 Sec.

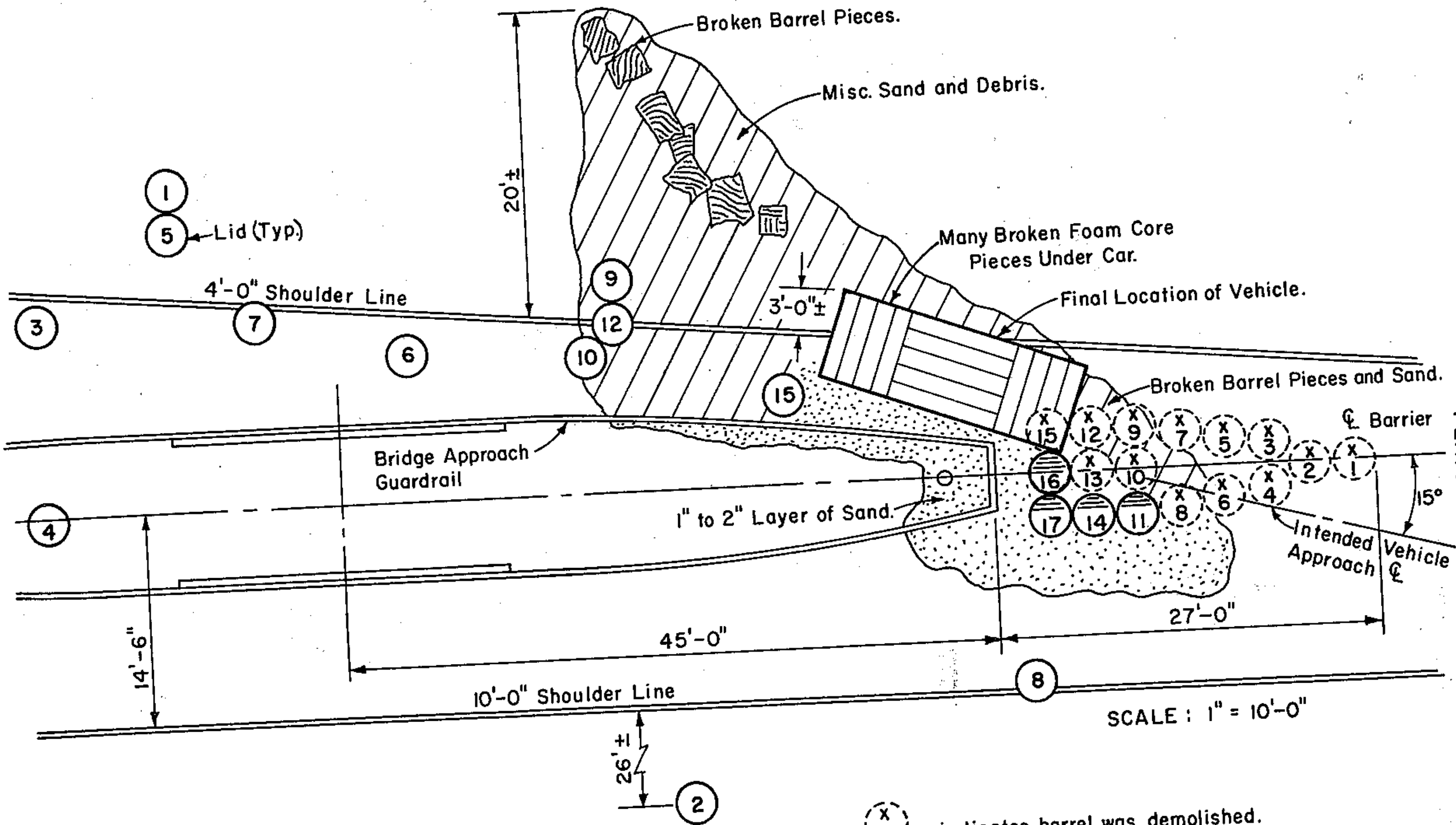


Impact + 8.880 Sec.

Test No.	243
Date of Test	September 24, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummy & instrumentation)	4770 lbs.
Impact Velocity (V_o)	57 mph
Impact Angle	15° nose
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17

Deceleration Distance - Passenger Compartment	39'-0"
Maximum Vehicular Deformation at Forestructure	1'-9"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 176 Hertz	7.9 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 39'-0" (stopping distance)	2.8 G's
Gadd Severity Index (Dummy's head)	580

PLATE 8



NOTES:

1. Many small, broken foam core pieces blown in all directions by wind.
2. Barrels 11, 14, 16 & 17 still upright, but squashed out of shape with lids still on.
3. Vehicle struck barrier 1 foot to right of intended vehicle approach centerline.
4. (x) x indicates barrel was demolished.
5. Shoulder width measured at last row of barrels.

DEBRIS LOCATION DIAGRAM
TEST 243

VII. DISCUSSION

Summary of Test Parameters

Test Vehicle

Item	Test 241	Test 242	Test 243
Make	1968 Dodge sedan	1957 VW sedan	1968 Dodge sedan
Weight	4690 lbs.	1940 lbs.	4770 lbs.
Impact Velocity	58 mph	59 mph	57 mph
Type of Impact	Head-on	Head-on	Nose, 15° angle with barrier centerline
Dummy Restraint	Lap belt	Lap belt	Lap belt

Test Barrier

Nominal Length	21'	25'	25'
Space between Barrier and Fixed Object	1'	2'	2'
Number of Cylinders	15	17	17
Nominal Weight of Cylinders	400-2100 lbs.	200-1400 lbs.	200-1400 lbs.
Density of Sand	80 pcf	88 pcf	89 pcf

Vehicular Deceleration

The records of vehicular longitudinal deceleration for Test 242 contained four distinct pulses spaced about 50 milliseconds apart. All were in the 10 G range with valleys of about 5 G's (see Appendix E). This pulsing occurred as the vehicle went from one row of barrels to the next. The over-all shape of the deceleration data indicated that this barrier configuration (Test 242) was better than that used for Test 241 (a row of 2- 700 lb. barrels followed by 3- 1400 lb. barrels in the midsection of the barrier). This abrupt change in barrier mass for Test 241 coincided with the 15 G 5 ms vehicular deceleration which occurred as the vehicle passed the midsection of the barrier (see Appendix E). For Test 242, the midsection of the barrier had 2- 700 lb. barrels followed by 2- 1400 lb. barrels and then by 3- 1400 lb. barrels -- a smoother transition of mass which was reflected in the deceleration data. The 200 lb. barrels at the barrier nose in Test 242 helped to soften the impact of the VW, but even so the VW decelerated faster than the Dodges in Tests 241 and 243.

The vehicular longitudinal decelerations for Test 243 were fairly constant at 7-9 G's with several main pulses and were similar in magnitude and shape to those for Test 242, thus showing that the barrier configuration, which was identical for both tests, had a similar effect on cars with different weights. The deceleration pulse was decaying as the vehicle passed through the last two rows of 1400 lb. barrels; thus it appeared that these last rows had already been set in motion by the time the vehicle passed through them and, therefore, had a low decelerative effect. The vehicle had a velocity of about 14 mph as it penetrated the last row of barrels; hence, the barrier did not have enough mass and/or width to stop a 4770 lb. vehicle impacting near the nose at 15° and 57 mph.

A summary of the vehicular passenger compartment highest 50 ms average decelerations measured during each test is shown in Table 1 below. (The lateral decelerations measured were negligible so only the longitudinal decelerations are presented here.)

TABLE 1

Vehicular Decelerations

Test	Highest 50 millisecond average values of longitudinal deceleration in G's
241 (one accelerometer)	10.7
242 (average of two accelerometers)	8.7
243 (average of two accelerometers)	7.9

The severity of these decelerations can be interpreted by comparing them with the recommended 200 ms deceleration tolerance limits proposed by Cornell[8]. These Cornell limits, which were 5 G's, 10 G's, and 25 G's for unrestrained, lap belted, and fully restrained occupants, define what would be, in the opinion of the researchers, a survivable environment under almost all circumstances when applied to a 50 ms time interval. Thus the vehicular passenger compartment decelerations in the longitudinal direction were judged acceptable for restrained passengers. Only in Test 241 did the computed value slightly exceed the maximum value of 10 G's for lap belted passengers. However, unrestrained passengers or lap-belted passengers in a passenger compartment with unyielding surfaces could not be furnished with similar protection by the barrier without greatly increasing the length of the barrier. Nevertheless, these more vulnerable passengers would experience decelerations well below those that would be experienced during collisions with a fixed object[7].

The vehicular decelerations were also under the value of 12 G's for the highest 40 ms period, a criterion established by the Federal Highway Administration[6].

Computed values of the Gadd Severity Index indicate that in one test, Test 242, the dummy driver might have suffered fatal head injuries. Therefore, acceptable vehicular decelerations, based on the criteria described above, do not automatically confer immunity to fatal injuries.

The unfiltered and filtered records of vehicular longitudinal deceleration showed less ringing for Test 242 with the VW than for Tests 241 and 243 with the heavier Dodges. This may have been due to the softer "unitized" construction of the VW and/or the absence of a rigid engine and other parts in the vehicle forestructure.

Decelerations - Dummy

The dummy decelerations for Test 242 were much higher than for Tests 241 and 243. A comparison of the vehicle velocities at the time after impact when head decelerations were maximum indicated that the VW was traveling about 46 ft. per second and the Dodges about 51 ft. per second; hence, the relative dummy head velocity was 15% higher in the VW if the head was still traveling at an absolute velocity of 85 ft. per second, the average impact velocity of the cars. This would account for some of the difference. The harder interior surfaces impacted in the VW were probably mainly responsible for the higher head deceleration.

Gadd Severity Index

Longitudinal, lateral, and vertical components of deceleration from the dummy's head were vectorially combined at identical times after impact (at successive 0.0025 second increments) to obtain resultant values of deceleration. Then the Gadd Severity Index[9], $\int_{t1}^{t2} a^{2.5} dt$, was computed over the 50 millisecond period with the highest average resultant values of head deceleration using 20 successive time intervals with dt = 0.0025 sec. Table II, below, contains a summary of the Severity Indices calculated for the tests reported herein:

TABLE II

Gadd Severity Index

Test Number	Gadd Severity Index
241	185
242	1280
243	580
Recommended Tolerance Limit	1000

The Gadd Severity Index of 1280 in Test 242 indicated that even a lap-belt restrained passenger probably would have suffered fatal head injuries if his head struck the windshield frame as violently as did the head of the dummy. This high number was not surprising in that the head of the dummy broke the windshield and forced it entirely out of the car, then went on to make a dent near the small radius edge of the unpadded stiff metal dashboard. The steering wheel had been removed to accommodate the remote steering apparatus. If it had been in place, it might have minimized the impact severity when the dummy struck the dash; however, a front seat passenger, with no steering wheel in front of him, might normally impact the dash like the dummy driver did. This reinforces the idea that the injuries sustained by the vehicle occupants in a 60 mph collision with an energy absorbing barrier are dependent on the impact protection provided by the vehicle interior surfaces if ejection does not occur and both a lap belt and a shoulder harness are not in use. See Appendix D for a discussion of this Severity Index and the tolerance of the human head to deceleration.

Debris

In all tests, the foam plastic core material that supported the sand in the barrels was broken into small pieces. This material did not land in the traveled way initially, except after the angular impact in Test 243; however, the pieces were so light that the slightest breeze blew them all over the test site. If this material was used in operational barrier installations, it could pose a severe litter and maintenance problem after barrier impacts. In addition, this material could create a psychological hazard to nearby motorists, even though it is lightweight and harmless.

The barrel lids were another source of debris. After impact, they sailed through the air for distances up to 100 feet. Most of them stayed in the gore area during the head-on impacts but the few which landed in the traveled way posed a potential psychological hazard for nearby motorists. In Test 242, the cotton sash cord which was threaded continuously through all the lids and anchored at the rear of the barrier proved to be an effective method of keeping all the lids in the gore area. However, the cord gave the barrier a slightly less desirable appearance.

Broken barrel pieces and sand were mostly contained in the gore area except during the angular impact of Test 243. In Tests 241 and 243 the Dodges tended to ramp over that debris, especially so in Test 241 where the rear of the barrier was only 12" from the bridge approach guardrail. The VW did not ramp up because of the sloping forestructure of the vehicle, which tended to nose under the sand in the front barrels of the barrier.

The debris scattered in the traveled way after an angular impact such as Test 243 appears to be one presently unsolved drawback of this barrier.

Barrier Dimensions

The test barriers were close to the minimum length required to provide reasonable safety for restrained passengers in vehicle impacting at 60 mph, based on the instrumentation data results. The barrier could be increased in length to provide a softer impact; however, this would remove possible recovery area. Site conditions would partially govern the decision regarding optimum barrier length. Initial and maintenance costs would vary with the length of the barrier.

Redirection

In all the tests, including Test 243 which involved an angular impact, the vehicle was not redirected but continued on a straight course after impacting the barrier.

Sand Density

The sand used in the barrels was sampled during barrier construction. Subsequent test results indicated that the density was significantly lower than the nominal 100 pcf unit weight assumed by the manufacturer, as can be seen in Table III, below:

TABLE III

Sand Density

	Density	Water Content
Manufacturer	100 pcf (assumed)	Unspecified
Test No. 241	80 pcf	7.6%
Test No. 242	88 pcf*	0.4%*
Test No. 243	89 pcf*	0.8%*

*Sand was run through a dryer just before delivery.

Reference 10 gives the general range of unit weights for dry, loose sand as 90-100 pcf, and for damp loose sand as 85-95 pcf. Thus, the sand used for the barriers tested fell just below the lower end of the normal weight range. Reference 10 also contains graphs showing how sand volume increases by 15 to 35% (max.) for coarse to fine sand, respectively, with moisture contents from 0-20%.

It was concluded that it would probably be too bothersome and an added expense to have sand dried for operational barriers. The added weight of the dried sand would not change the effectiveness of the barrier significantly; however, it is well to realize that sand density is a variable factor and that if sand with a density of 100 pcf was used in a barrier, the performance could differ somewhat from that reported herein.

Aesthetics

This barrier presents a low, relatively uniform shape. The barrels can be ordered in bright or dark colors. Care should be taken to provide a level site so that the barrels will not lean at random angles. For those who do object to the imposition of bright cylindrical shapes on the streamlined highway profile, a cover for the entire barrier might be desirable. Any cover selected should be a weather resistant, taut, flexible material and should not inhibit the free movement of the sand during impacts. Material wrapped around the sides would be preferable to a complete cover until full scale tests of barriers with covered tops are conducted.

Accident Experience

Accident reports from Connecticut indicate that fifteen in-service barriers were impacted sixteen times[3]. In thirteen cases, the vehicle was driven away before accident information could be gathered. Several of these impacts were nuisance hits. However, it was reported that the barrier may have prevented an impending collision with a fixed object in many of these cases. The three remaining reported accidents were all serious, yet in all cases the drivers received only minor injuries and it was clear that the barrier prevented a calamitous crash into the fixed object. One of these crashes, which occurred during wintertime, resulted in the vehicle ramping somewhat and rolling off to the side of the barrier. This undesirable vehicle behavior was attributed, for the most part, to the fact that the sand was frozen. Thus a sand-salt mixture has been recommended for barriers placed in locations susceptible to temperatures below 32^{o} F.

The manufacturer reported in December 1970 that there were 102 barrier installations in 18 states and Canada[11]. There had been 37 impacts of the barrier at speeds up to 65 mph with no "injuries", and the probability that several lives were saved according to the accident reports. In 80% of these impacts, the vehicle was driven away and the accident was not reported. About 10% of the crashes were head-on into the barrier; the remainder were sideswipes or angular collisions.

Design Considerations

Barrier size and configuration must be selected for each site. The barrier configuration will depend on (1) the width of fixed object to be shielded, (2) the predicted speed and angle of the impacting vehicles, and (3) the available space in the gore, shoulders, and traffic lanes. The presence of curbs and guardrails may also affect the design. A curb immediately in front of the barrier nose could adversely affect the barrier performance because the vehicle may vault over the curb, thus preventing the vehicle from impacting the modules at the optimum height for vehicle stability and uniform deceleration. Such a curb should be removed.

The width of the back row of modules should always be greater than the width of the fixed object. This will soften the impacts of those vehicles striking the rear portion of the barrier at an angle and provide some deceleration prior to striking the corners, if any, of the fixed object. The barrier modules should be set back from the traffic lanes to minimize the number of casual vehicular contacts with the barrier and the amount of debris thrown into the traveled way when an impact does occur. Also, space should be left behind the last row of modules so the sand and debris will not be confined and increase the ramping effect of the vehicle.

The lower foot of sand in the 2100 lb. modules provides additional mass as a backup for the front of the barrier. However, the velocity of the vehicle at the time it makes direct contact with the back row of the barrier is not sufficient to explosively displace this sand. Consequently, it is displaced very little and thus tends to form a ramp. The use of 1400 lb. modules in place of 2100 lb. modules in the last row would therefore be desirable to eliminate this relatively ineffective lower foot of sand.

When fixed objects are more than 6' wide, extra longitudinal rows of modules may be added to the barrier. The first few modules in each of these rows should be no more than 3' apart (clear dimension) in the lateral direction. Then impacting vehicles, most of which have an average width of 6', will displace approximately the same mass of sand whether they hit one longitudinal row of modules head-on or carry away one half of each row on either side. Depending on available space, modules may be separated by any distance in the longitudinal direction. Extra distance will lower the deceleration rates.

A recent report (Reference 3) stated that some nonimpact failures of these cores had occurred when they were placed on sloped gore areas. The failures occurred only when the strong axis of the core material was perpendicular to the cross slope and consisted of collapse of the core.

To prevent this, the strong axis of the foam plastic core blocks should be placed parallel to the cross slope to prevent collapse of the core due to barrel movement down the cross slope induced by traffic vibrations. Also, the manufacturer is studying new core block configurations and new core materials. It might prove advisable to enclose cores made of light, crushable foam plastic with a flexible fine-mesh bag to limit their scatter after a barrier impact.

If placed in climates subject to temperatures below 32° F, the addition of at least 5% road salt to the sand should be specified to preclude solidification of the moist sand.

The barrier site should have a relatively uniform slope so the barrels will not lean at unaesthetic, random angles. A paved surface is ideal. The maximum lateral slope of the gore area should be 5%. The bottoms of the barrels can be cut off at an angle with a saw so they will stand vertically; however, this must be done carefully to maintain a good appearance.

Snow at the barrier site should be plowed away from or beyond the gore area to maintain barrier effectiveness.

A thin wire or rope may be threaded continuously through all module lids and anchored to the ground at the rear of the barrier to minimize dispersal of lids during impact (Test 242).

A recommended minimum optimum barrier length would be 21' to 24'. This length provides survivable deceleration levels for 60 mph impacts without taking away excessive recovery area for errant vehicles.

Implementation

Two Fitch barriers have been installed, on a trial basis, on California state highways to date. Several additional trial installations are planned for the near future. Additional barriers will be installed, on a trial basis, at those locations that appear to be well suited to the use of a low (first) cost, nonredirecting energy absorbing barrier.

VIII. REFERENCES

1. Nordlin, E. F., Woodstrom, J. H., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Water-Filled Cells, Series XXI", California Division of Highway, November 1970.

2. Nordlin, E. F., Woodstrom, J. H., and Doty, R. N., "Dynamic Tests of an Energy Absorbing Barrier Employing Steel Drums, Series XXII", California Division of Highways, October 1970.

3. Kudzia, Walter J., Schwegler, Lee T., and Hough, Michael, "The Fitch Inertial Barrier and Its Performance in Connecticut".

4. Nordlin, E. F., Woodstrom, J. H., and Hackett, R. P., "Dynamic Tests of the California Type 20 Bridge Barrier Rail, Series XXIII", California Division of Highways, October 1970.

5. "Federal Motor Vehicle Safety Standards", National Highway Safety Bureau, U. S. Department of Transportation, with amendments and interpretations through August 6, 1968.

6. "Development of a Hydraulic-Plastic Barrier for Impact-Energy Absorption", BPR-DOT Contract No. FH-11-6909 Final Report, Department of Mechanical Engineering, Brigham Young University.

7. Hayes, G. G., Ivey, D. L., and Hirsch, T. J., "Performance of the 'Hi-Dro Cushion' Vehicle Impact Attenuator", Technical Memorandum 505-11, Texas Transportation Institute, August 1970.

8. "Highway Barrier Analysis and Test Program", Summary Report for period July 1960 - July 1961, Cornell Aeronautical Laboratory Report No. VJ-1472-V-3, July 1969.

9. "10th Stapp Car Crash Conference - Proceedings", November 8-9, 1966, published by Society of Automotive Engineers, Inc. Paper 660793 by Charles W. Gadd, "Use of a Weighted-Impulse Criterion for Estimating Injury Hazard"; Paper 660803 by Alan M. Nahum, M.D., Arnold W. Siegel, and Stanford B. Trachtenberg, M.D., "Causes of Significant Injuries in Nonfatal Traffic Accidents".

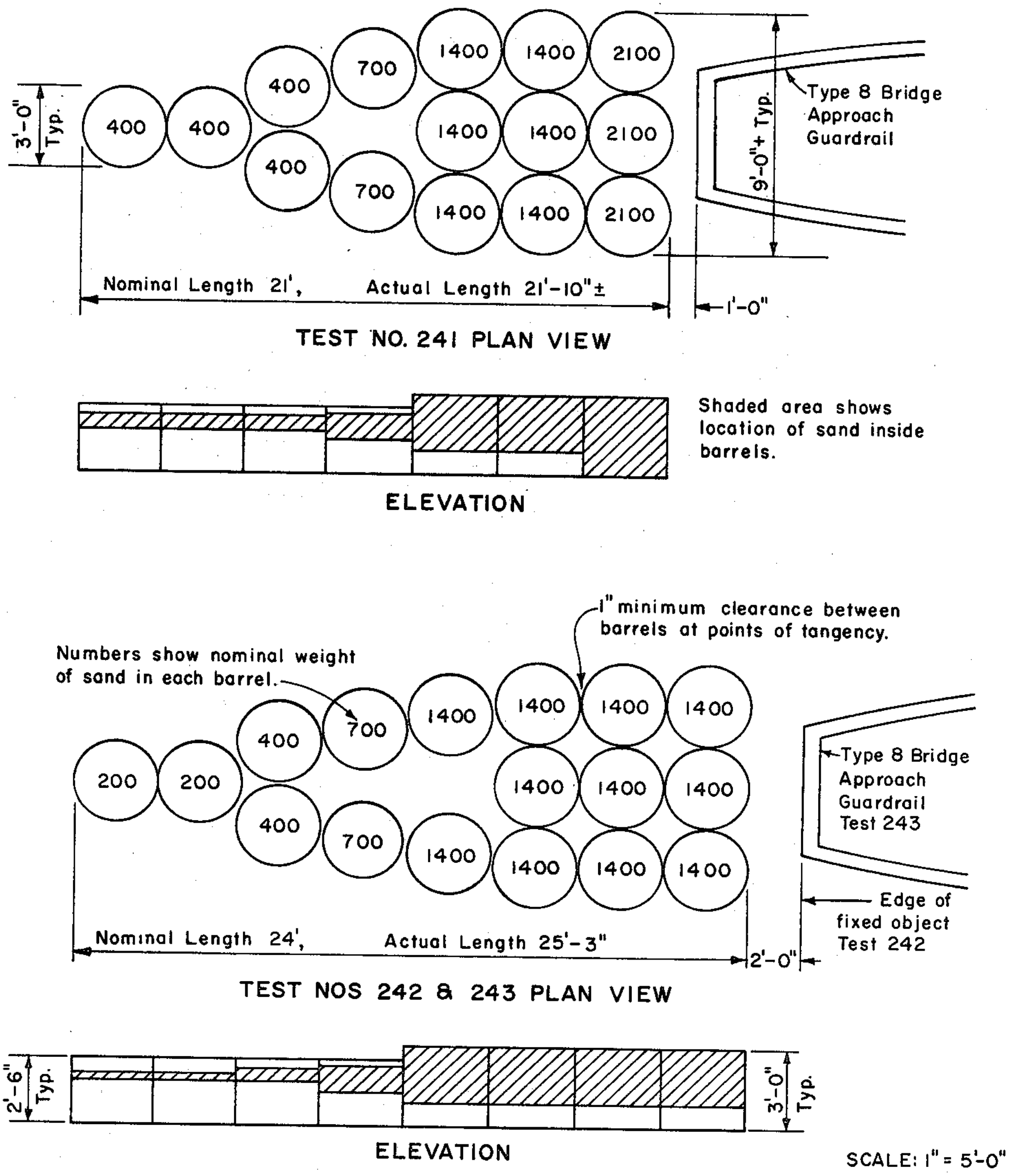
10. "Concrete", Troxell and Davis, McGraw Hill Engineering Series, 1956.

11. Letter from C. C. Walter, Fibco Inc., dated December 30, 1970.

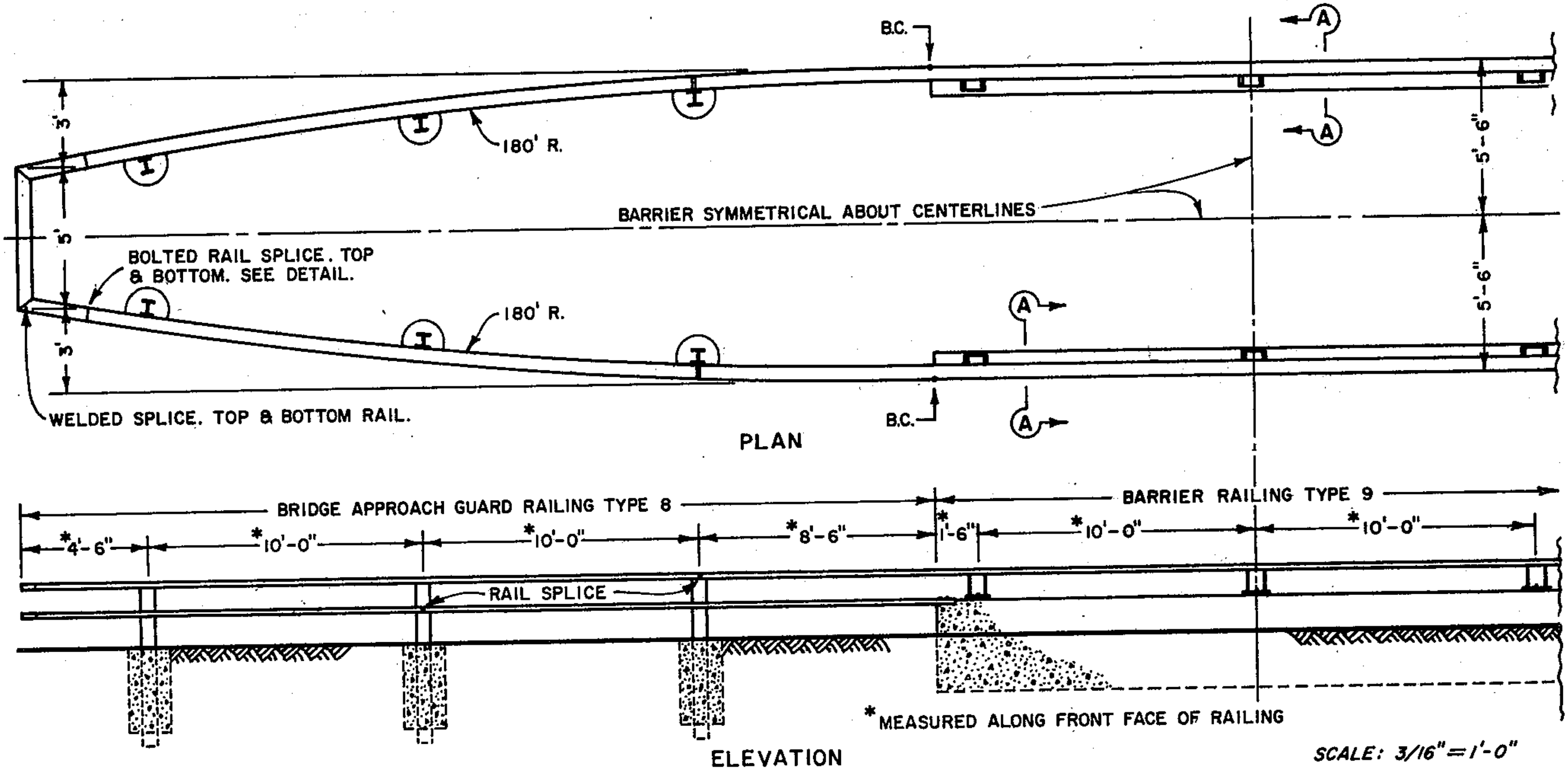
12. "The Seventh Stapp Car Crash Conference - Proceedings" edited by Derwyn M. Severy, Charles C. Thomas, publisher, 1965.

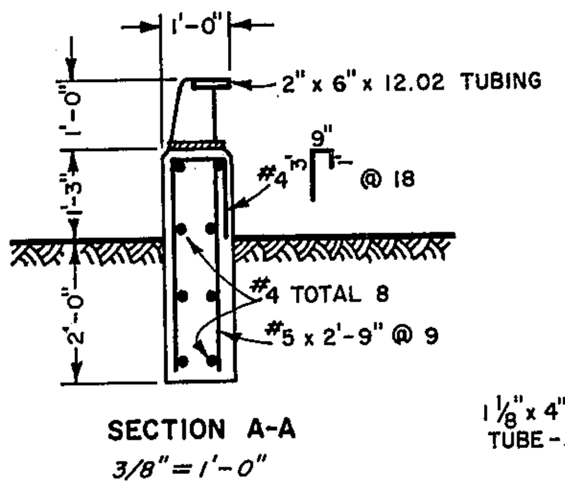
13. "Proceedings, General Motors Corporation Automotive Safety Seminar", General Motors Safety Research and Development Laboratory, July 11-12, 1968.

EXHIBIT 1



TEST BARRIER PLANS





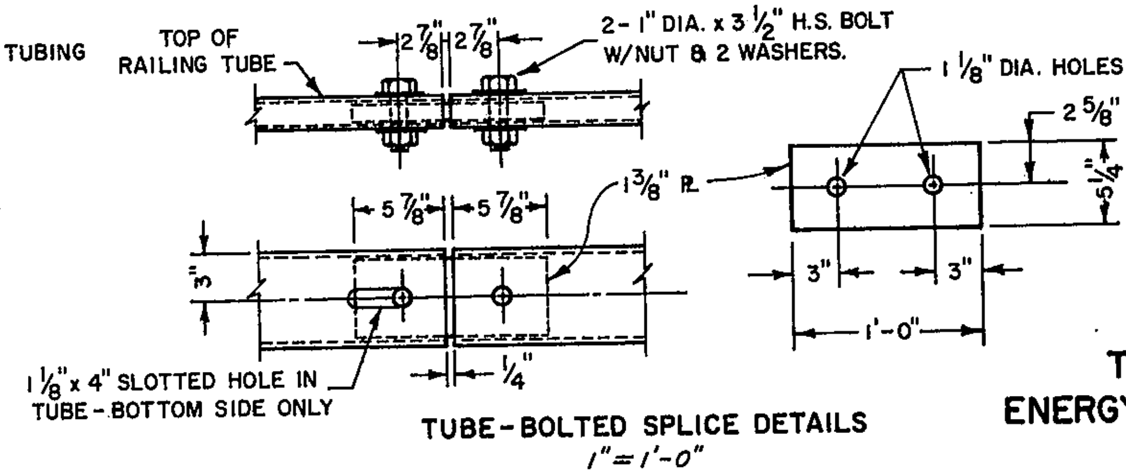
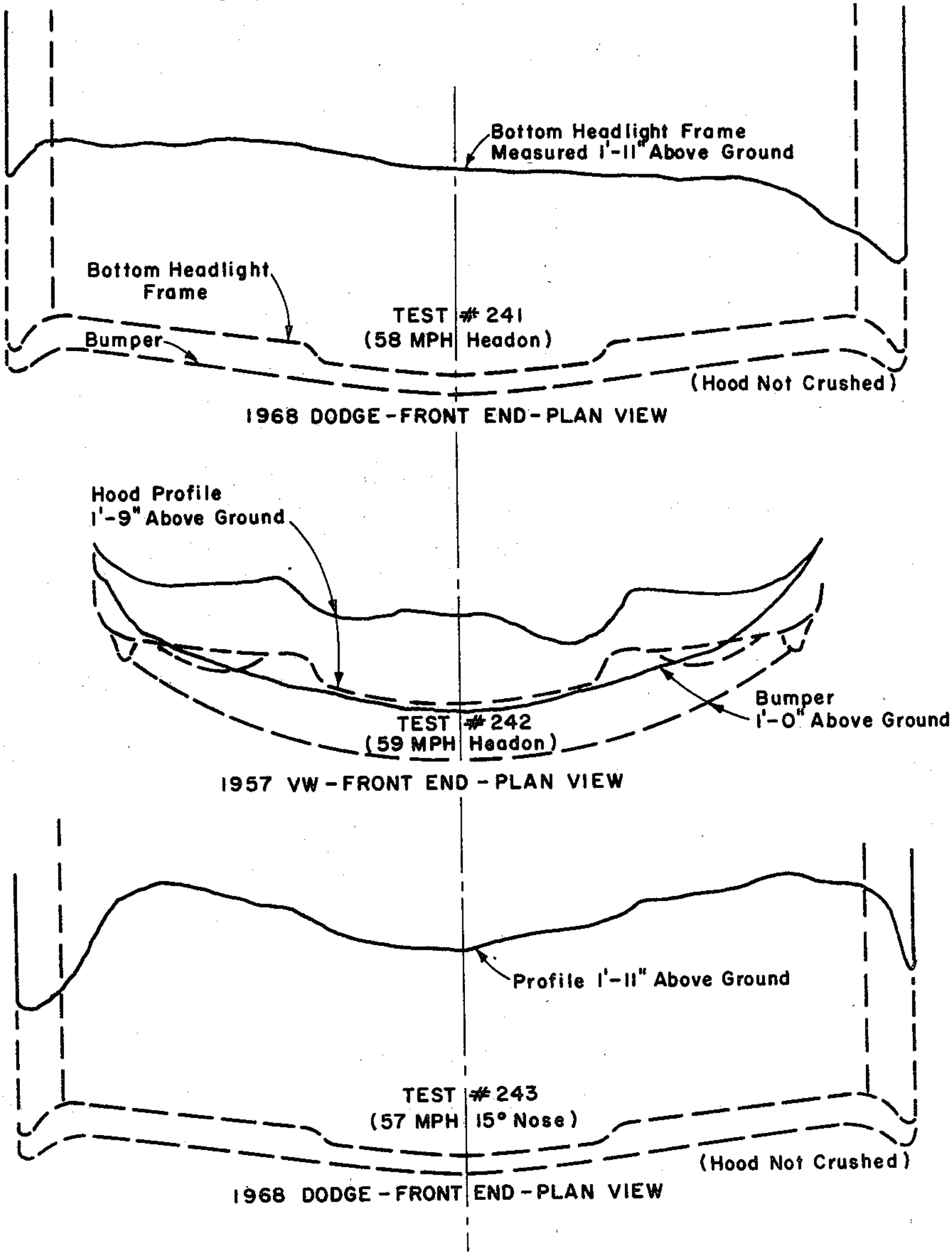


Exhibit 2

TYPICAL GORE –
ENERGY ABSORBER TESTS

EXHIBIT 3

VEHICULAR CRUSH
SAND-FILLED BARREL ENERGY ATTENUATOR



Dashed lines show precrash profiles.

Scale 1" = 1'-0"

APPENDIX A

Volkswagen Tow System - VW

The Volkswagen was incapable of accelerating to 60 mph under its own power within the confines of the test site. Thus, the VW was steered and braked by radio control from a follow vehicle, as was done in the other two tests; however, a cable tow system was devised to accelerate the VW.

The equipment for this tow system included the following:

1. A pulley was mounted on top of each of two concrete anchors cast in the ground. The anchors were 2'-6" in diameter and 5'-0" deep and strengthened with a reinforcing steel cage. The ductile iron pulleys were 12 inches in diameter and had Timken bearings, a 1½" pin diameter, and a groove for 5/16" wire rope (Figure A-1).

2. A pulley like those described in "1" above was attached to the back of a 1968 Dodge which was used as the tow vehicle (Figure A-2). All three pulleys had guides to keep the cable from jamming or slipping out of the pulley groove.

3. A pintle hook was mounted on a third cast-in-place concrete anchor to act as a deadman (Figure A-3).

4. A pintle hook was also attached to the front end of the VW (Figure A-4).

5. The tow cable used was preformed, 5/16" wire rope with an independent wire rope core. The cable was 1100 feet long. Two loops of wire about 1/8" in diameter were used as a weak link at each end of the cable to attach it to the pintle hooks on the VW and the deadman anchor.

6. Wire rope 3/16" in diameter was used as a tether line to release the trigger on the pintle hook of the VW about 20' in front of the first ground pulley and to release the pintle hook trigger at the deadman when the VW was about 10' in front of the first ground pulley. The first tether line was tied at its other end to a long bolt driven into the asphalt concrete runway and the second tether line was tied at its other end to the tow vehicle. Both tether lines had weak links at their attachment to the pintle hooks which consisted of three loops of twine. The runway was cleared of all projecting nails, rocks, etc. to prevent the tether lines from snagging and prematurely releasing the pintle hook triggers.

The numerous weak links were provided in case the cable jammed or other malfunctions occurred in the system.

The reverse tow system that was used enabled the tow vehicle to travel at half the speed of the VW. These two vehicles ran on diverging lines, rather than parallel, as an added safety factor (see Plate A-1, following page). A trial and error method was necessary in order to select weak links for the cables that would sustain normal loads during the test and yet fail when the load was increased moderately.

A linear actuator was used on the tow vehicle accelerator to keep the acceleration smooth and constant and to insure an impact velocity of the VW near 60 mph based on trial runs which were used to calibrate the actuator.

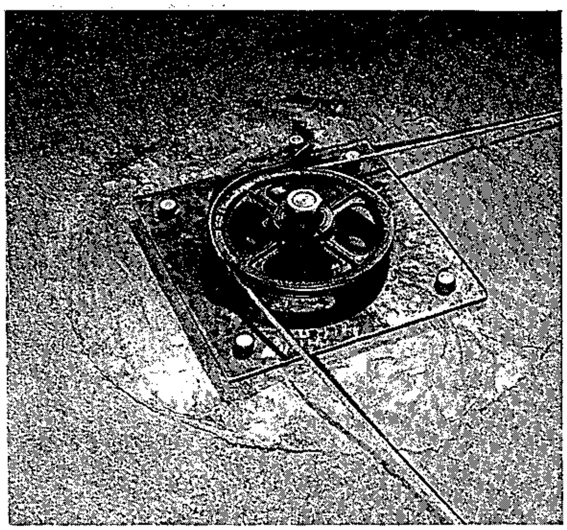


FIGURE A-1

FIGURE A-2

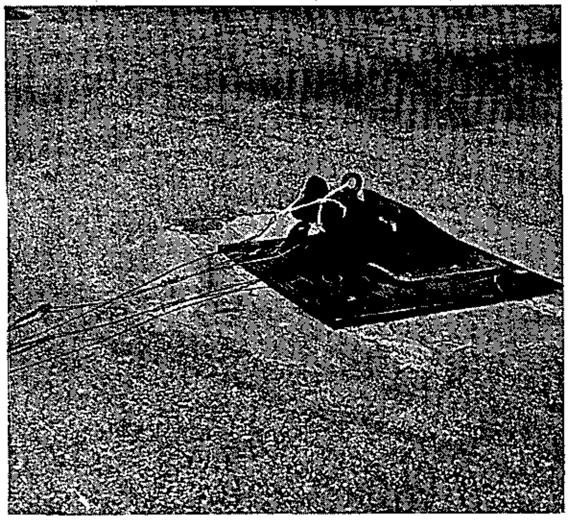


FIGURE A-3

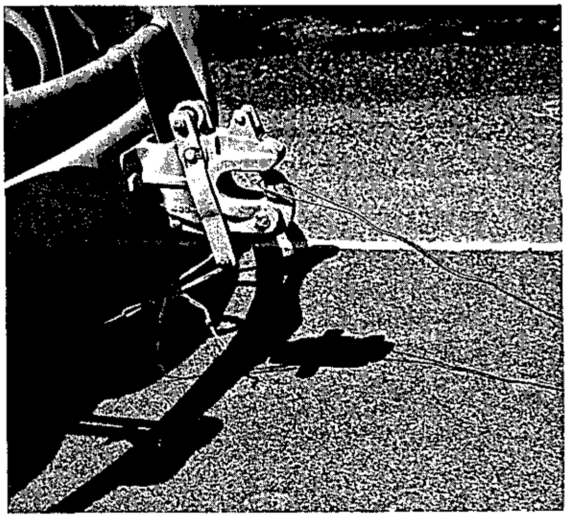
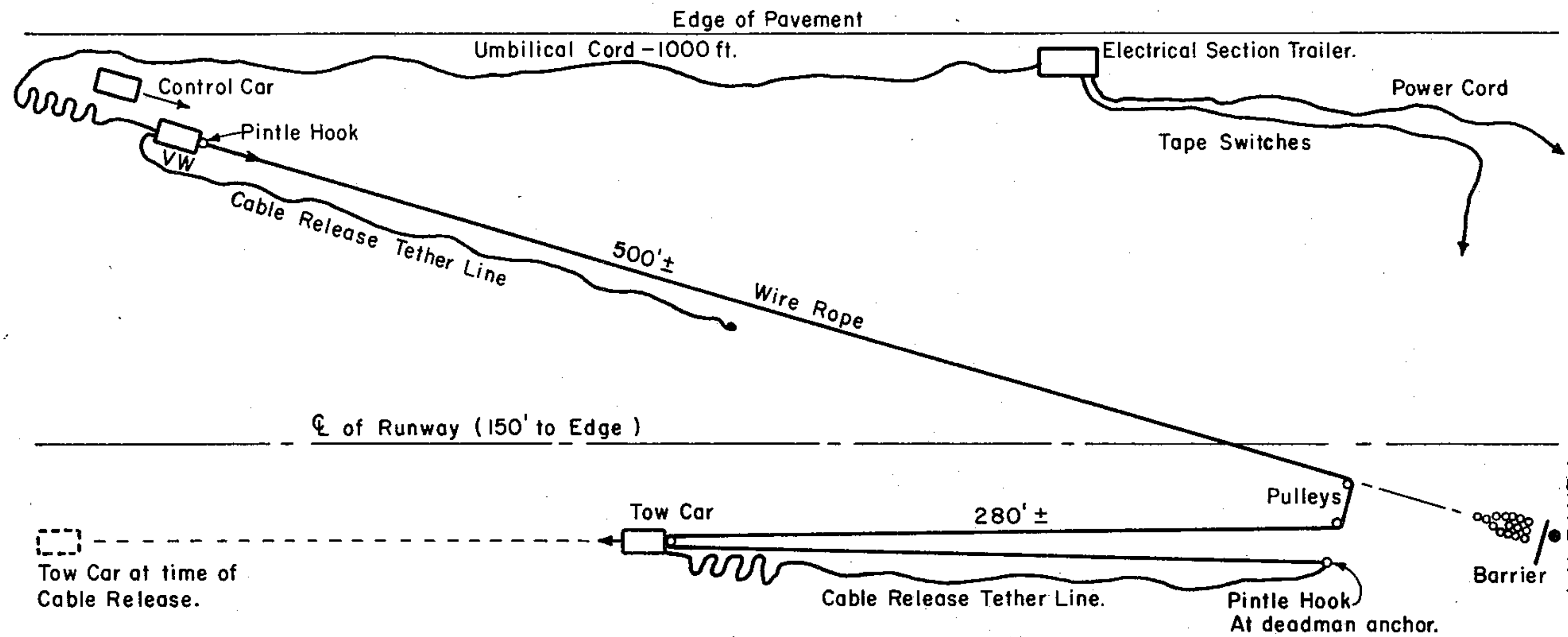


FIGURE A-4

PLATE A-1

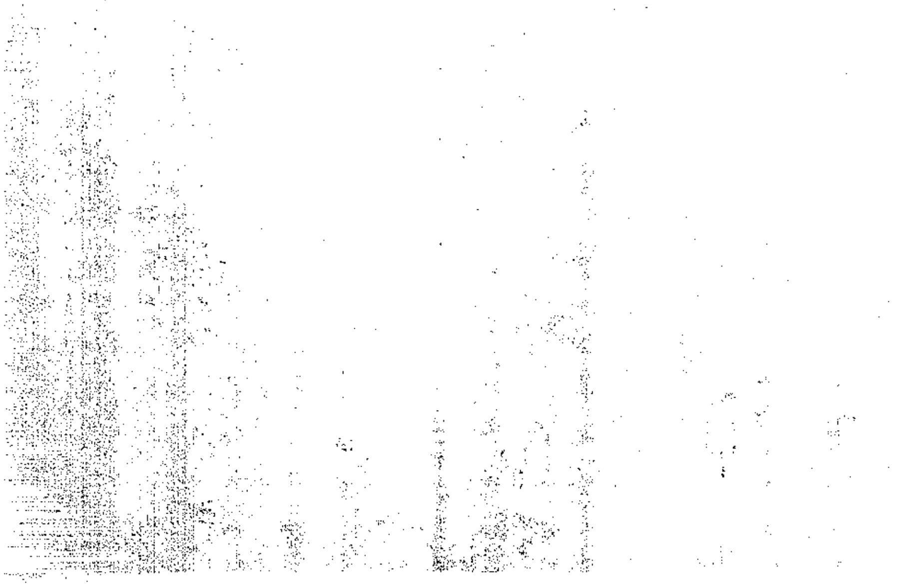


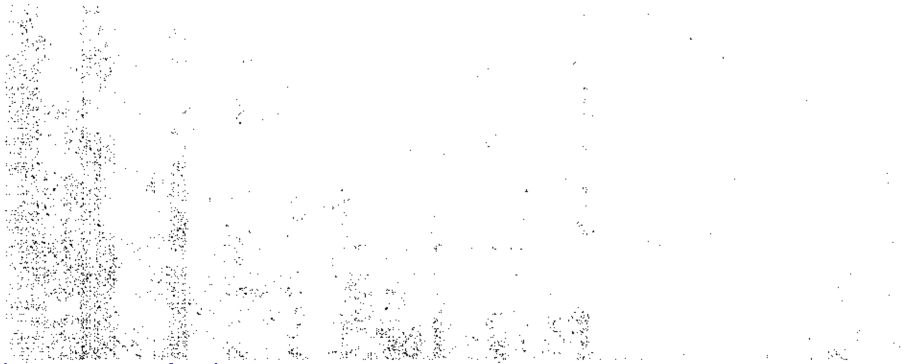
NOTE:
1. CONTROL CAR STOPPED ON LINE.
2. WEAK LINKS PROVIDED AT EACH END OF WIRE ROPE AND AT EACH TETHER LINE.

VW CAR TOWING EQUIPMENT LAYOUT

TEST 242

NO SCALE





APPENDIX B

A. Instructions for the Assembly and Installation of Barriers

1. Site preparation. Level the ground, eliminate soft ground if possible, and locate the barrier outline.

2. Assemble barrels. They are shipped nested together in semi-circular halves. Hold longitudinal edges of two halves together and rivet with a hand gun. Use a washer on each rivet.

3. Place the back row of barrels in position. Leave a one-inch clearance between them for ease in placing lids. Insert a circular disc at the bottom if barrel is on soft ground. Fill barrels with sand if these are 2100 lb. units. Spray paint can be used around the bottom of the barrels for future reference if they have to be replaced after a vehicle impact. The nominal weight of sand to be placed in the drum can also be noted with paint or the pavement.

4. Assemble cores, discs, and seals for one transverse row of barrels at a time. For all barrels other than 2100 lb. units, the proper foam plastic core support blocks must be selected, assembled, and placed in the bottom of the barrel. A circular hard plastic disc and a flexible clear plastic seal go on top of the core.

5. Place sand to the depth required for the predetermined weight. Sand density should be checked. Adjust barrier design if less than 85 pcf.

6. Thread continuous rope through all lids, if desired.

7. Attach lids. Rivet lids around the edge at four locations.

8. Place, assemble, and fill the next row of barrels as above and continue for each row out to the nose of the barrier.

NOTE: The barrel halves should be stored on end to prevent the semi-circular halves from opening up and developing a permanent set.

APPENDIX C

Notes on Assembly of the Test Barrier

Test 241.

Fifteen barrels were used. It took two men about two hours to rivet the barrel halves together. It took a crew of three men two hours to place the barrels, assemble the cores, place the sand, and rivet the lids on. The complete operation, then, took about 10 man-hours. The men were completely inexperienced and probably used more time than an experienced crew would require.

The sand (about ten tons) was delivered in one large dump truck which had a small guillotine type opening in the middle of the tailgate (see Figure C-1). The truck was positioned for each barrel, the truck bed raised, and the sand guided through the narrow tailgate opening. Two men moved sand in the truck bed and the third man spread the flowing sand evenly in the barrel. There was virtually no spillage of sand with this method

FIGURE C-1

The truck required a considerable distance in front of the barrier for maneuvering and backing. Assembly and placement of the cores, discs, and seals were hampered by a stiff breeze which made handling of the large area-light discs and cores difficult.

Test 242

The assembly procedure was similar to that used for Test 241. Total time required to assemble the barrier was about 11 man-hours. The sand was dried prior to delivery for this test in order to achieve a higher density. It flowed more easily from the dump truck into the barrels than the wetter sand used for Test 241; however, there was a great deal of dust and steam generated (the sand was still quite hot) which was obnoxious. There was a little more spillage than in Test 241 because the sand was so dry. In addition, the sand leaked through the plastic seals in several places until a shovel was chucked up and down in the sand to seal the holes.

Test 243

Construction of the barrier was accomplished in the same manner as for Tests 241 and 242. The work crew observed that there was less steam from the dried sand than for Test 242; however, they still had some trouble with the sand leaking through small gaps between the flexible plastic seals and the sides of the barrels. Assembly time was about the same as for Tests 241 and 242, i.e., 10-11 man-hours.

APPENDIX D

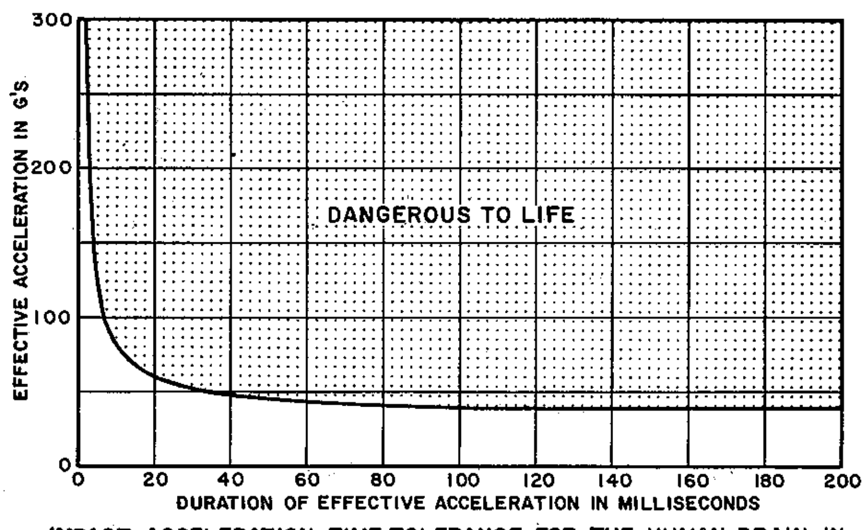
Head Deceleration Tolerance

Accelerometers were placed in the head of the dummy driver for all three tests in an effort to acquire some data, in addition to passenger compartment deceleration, that would give some indications of the chance of passenger survival of the impacts. The reasons for using this instrumentation were based on several references, the summaries of which follow:

Reference 9, Paper 660803, described a study of 150 accidents involving 223 vehicles, with 374 motorists, 239 of whom had a total of 496 "significant" injuries. In all cases, the motorist compartment remained intact and the injuries were sustained inside a late model passenger vehicle. It included passengers in all seat locations, all types of collisions and speeds of 0-60 mph with most from 10-40 mph. The head, neck, and face accounted for 53% of the 496 significant injuries, more than any other area of the body.

The areas struck by the vehicle occupants, in order of descending frequency, were the steering wheel column, instrument panel, windshield, and doors, all of which could cause head injuries, plus several other areas with a relatively low frequency rate. Other studies have produced similar conclusions.

Reference 12 describes tests with the heads of animals and cadavers that led to the deceleration tolerance curve shown on Figure D-1, below. This curve is based on a reversible concussion with no after effects. The 42 G asymptote was considered conservative because of the hard, unyielding surface used in testing. An 80 G limit was suggested if adequate padding is used on the area to be impacted.



IMPACT ACCELERATION-TIME TOLERANCE FOR THE HUMAN BRAIN IN FOREHEAD IMPACTS AGAINST PLANE, UNYIELDING SURFACES

FIGURE D-1

This work was the apparent basis for the Federal Vehicle Safety Standard requiring that a head form traveling at a relative velocity of 15 mph shall not exceed a deceleration of 80 G's continuously for more than 3 milliseconds when striking an instrument panel. Therefore, an energy absorbing barrier should decelerate a vehicle at a rate such that the relative velocity of a passenger's head will not be greater than 15 mph at the time of the secondary collision of the head with the vehicle interior.

Another paper describes a means of evaluating head impacts proposed by Charles Gadd of the G. M. Research Laboratories and called the Gadd Severity Index[9].

This index was developed after a study of the measurement of head injuries. A transducer was needed whose output was closely related to the mechanism of injury. The research group chose accelerometers, placed on the back side of the head, as the most practical, and, indirectly, a relatively good method for comparison with the most reliable research to date dealing with internal head injury, i.e., impact to the forehead that caused concussion.

It was concluded that peak acceleration did not relate directly to injury but rather that "injury was some function of both intensity of loading and its time duration" because the head is neither totally viscous nor totally brittle in its failure mode. Also observed was the fact that the limited number of deceleration tolerance studies available on men and animals all showed that tolerance to any given "G" level was in an inverse proportion to the duration of the deceleration. Therefore, no limiting "G" level could be chosen as a "criterion for the threshold of injury".

It was found that a straight line approximation on a log-log plot of deceleration magnitude with time provided a fairly good approximation of head injury severity over a range of between approximately one and fifty milliseconds.

Because the inverse of the slope of this line corresponded numerically with a simple exponential weighting factor, the injury threshold was defined as a single number. This exponential weighting technique thus takes into account the fact that the more intensive decelerations contribute to the injury severity to a disproportionately great degree. Thus, the following expression was developed:

$$SI = \int_{t_1}^{t_2} a^n \, dt$$

a = acceleration

t_1 = beginning of pulse

t_2 = end of pulse

n = 2.5 for head injuries

This expression can be used for various types of injury by varying the exponent (n). In the case for frontal head injury, with accelerometers on the head, the exponent was chosen as 2.5 and the limit on the Severity Index as 1000. The value of 2.5 was based primarily on the slope of the Wayne State University animal impact data representing dangerous concussion, but the Eiband - NASA curve has a similar slope. The selection of 1000 agrees with the NASA curve if square pulses are integrated, for example, 100 G's for 0.01 seconds, and it agrees with the Wayne State data if the irregular pulses from the original oscillograms are integrated.

Use of the Severity Index reduces differences in judgment which arise with interpretation of acceleration pulses which may have ringing, sharp spikes, and other irregular shapes.

Depressed Skull Fracture

Reference 13, G. M. Seminar (1968), Papers #8 and #9. These papers add some insight into head injuries. Head injuries are classified in three broad categories:

1. Concussion -- closed skull damage to the soft brain tissue -- called blunt object impact or inertial loading. This is a serious type and is the type mentioned above where the head is shown capable of resisting 80 G decelerations or a Severity Index under 1000.

2. Laceration -- cuts, tears, bruises to the soft tissue (hard, sharp object impact). This type would be much less likely to cause loss of life.

3. Depressed skull fracture -- (small contact area impacts). This is also a serious type -- considered to be hazardous with the onset of bone fracture.

Additional tests have been reported wherein a weight with one square inch of contact area was used to measure the strength of three areas of the skull. The results of this research indicated that even with a Severity Index less than 1000, if the contact area is less than one square inch, then serious head injury is possible. Thus, as was the case when evaluating impact severity using only passenger compartment decelerations, very severe injuries can be sustained during impacts rated as relatively mild in many instances.

APPENDIX E

Instrumentation Data

The following pages contain selected instrumentation data from all three tests reported herein.

The records that showed deceleration of the vehicular passenger compartment in Tests 242 and 243 were filtered at 176 Hertz and contained many high frequency spikes. The records were difficult to use for numerical computations so curves were faired in by hand over the filtered traces. Only these "hand faired" curves are shown on the attached plates. Numerical computations were then based on these faired-in curves.

The location of the accelerometers in the vehicular passenger compartment, Locations A and E, are shown more precisely on Plate 1, page 8.

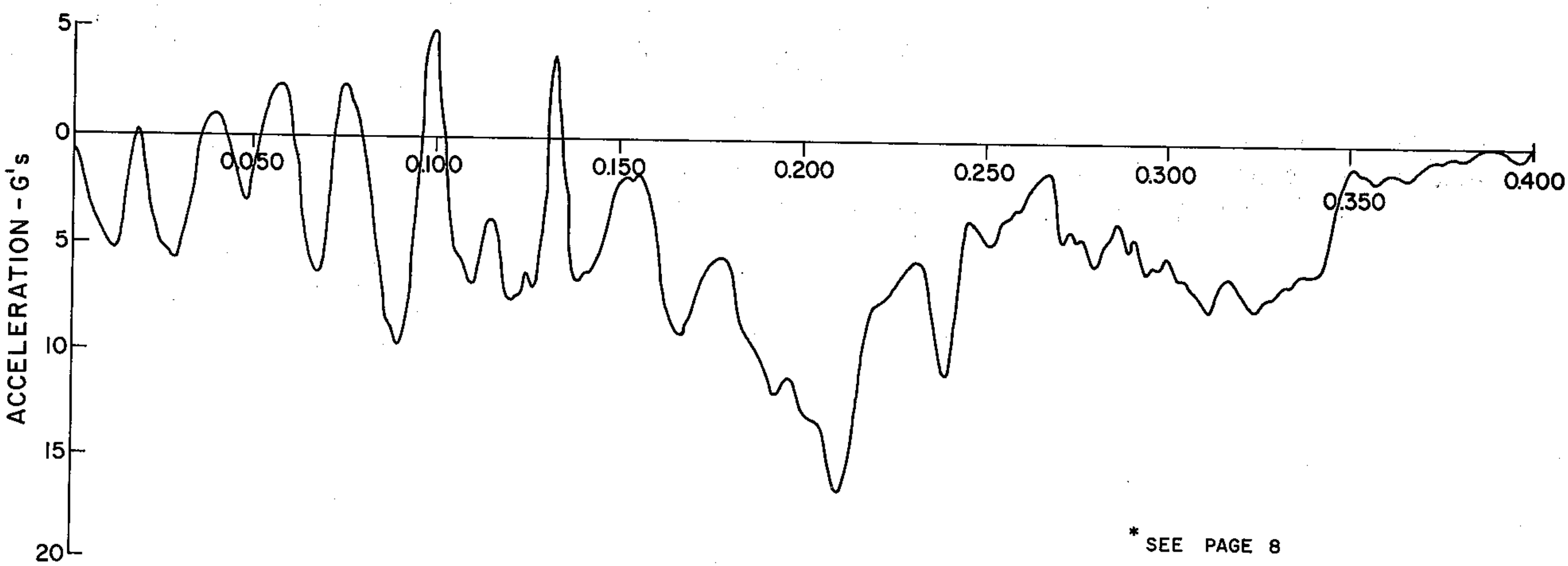
Accelerometers with a longitudinal orientation measured motion along the horizontal longitudinal axis of the test vehicle and those with a lateral orientation measured motion on a horizontal line perpendicular to the long axis of the vehicle. Accelerometers in the dummy were oriented similarly; however, they changed their orientation with respect to the vehicle axes when the dummy pivoted in an arc about its waist during impact.

ACCELERATION VS TIME

ENERGY ATTENUATOR-SAND TEST 241

58 MPH/HEAD-ON/4690 LB. DODGE

ACCELEROMETER
LOCATION E*-VEHICLE PASSENGER COMPARTMENT
ORIENTATION-LONGITUDINAL
FILTRATION RATE - 100 Hz.



* SEE PAGE 8

TIME AFTER IMPACT - Sec.

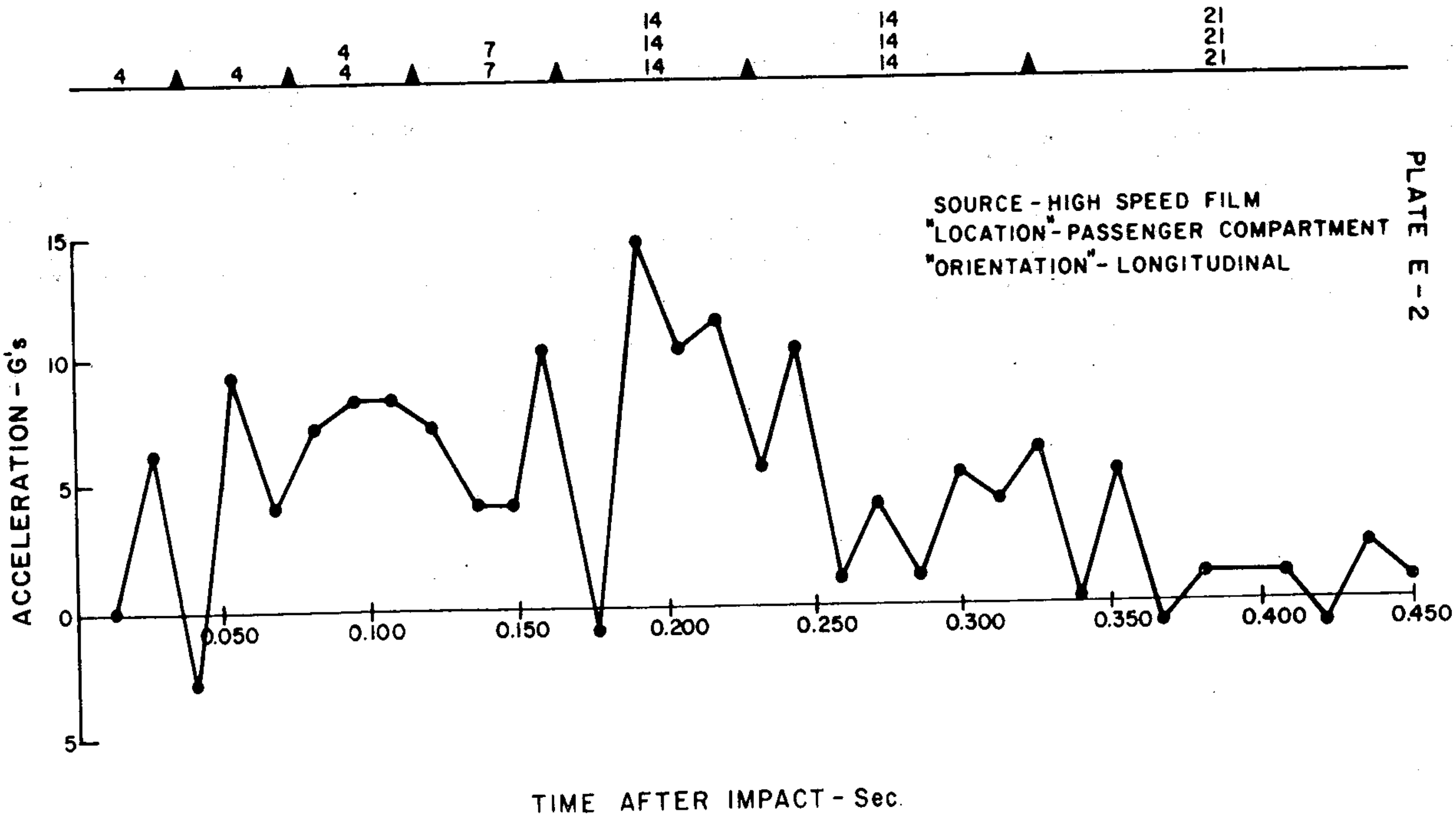
PLATE E-2

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH / HEAD - ON / 4690 LB. DODGE

LINEAR SCALES SHOW TIMES AT WHICH THE CRASH CAR PASSED THROUGH EACH THREE FOOT THICK ROW OF BARRELS. NUMBERS REPRESENT THE SIZE & NUMBER OF BARRELS IN EACH ROW

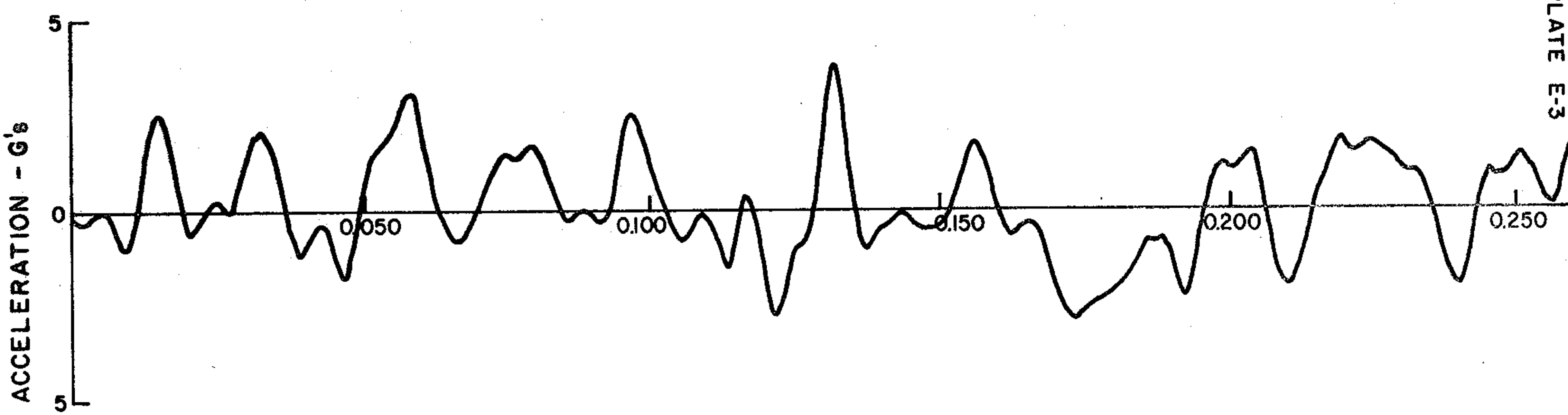


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH/ HEAD-ON / 4690 lb. DODGE

ACCELEROMETER
LOCATION E* - - - - VEHICLE PASSENGER COMPARTMENT
ORIENTATION - - - - LATERAL
FILTRATION RATE - 100 Hz.



*SEE PAGE 8

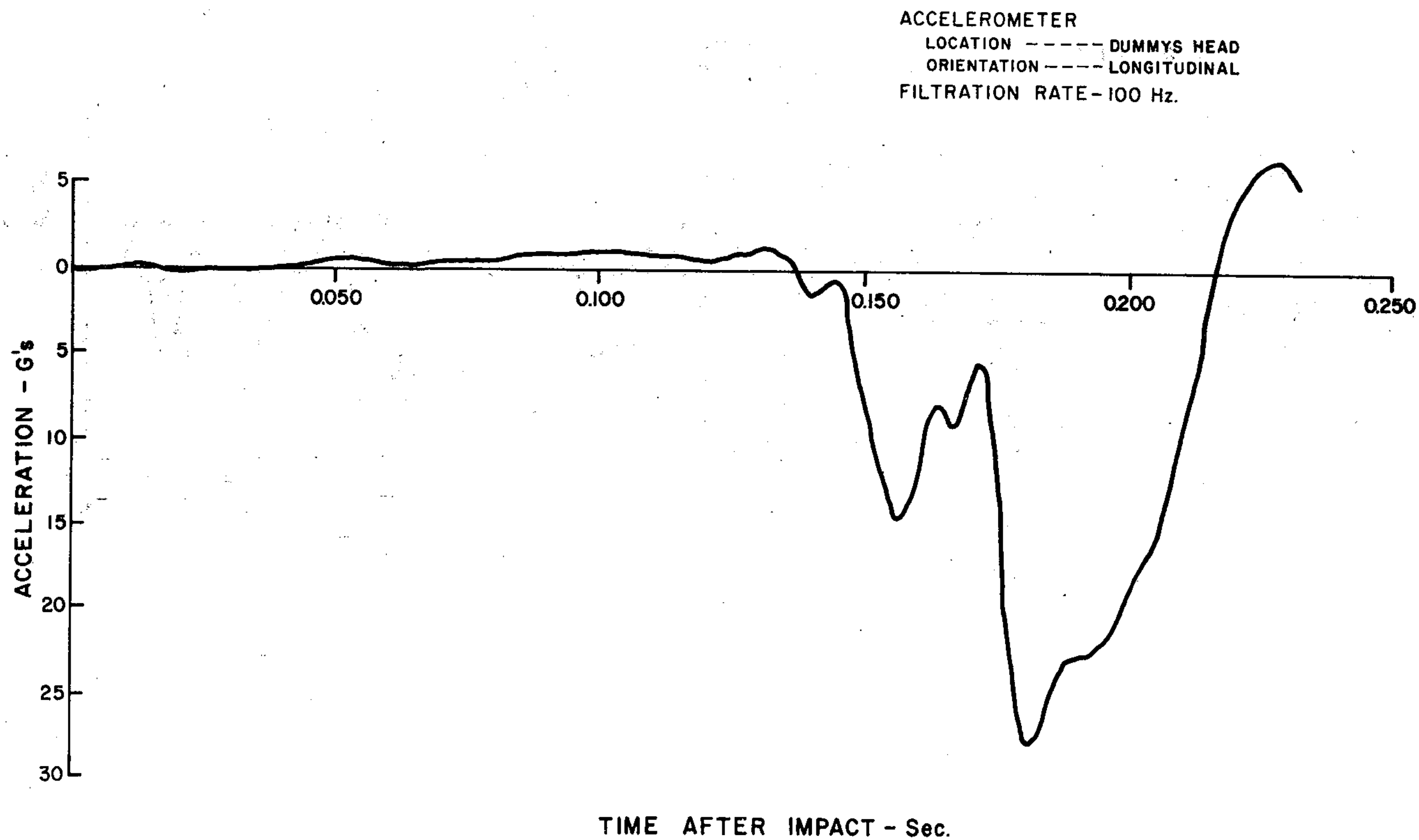
TIME AFTER IMPACT - Sec.

PLATE E-3

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH/ HEAD-ON / 4690 lb. DODGE



ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH/ HEAD-ON / 4690 lb. DODGE

ACCELEROMETER
LOCATION ----- DUMMY'S HEAD
ORIENTATION ---- VERTICAL
FILTRATION RATE - 100 Hz.

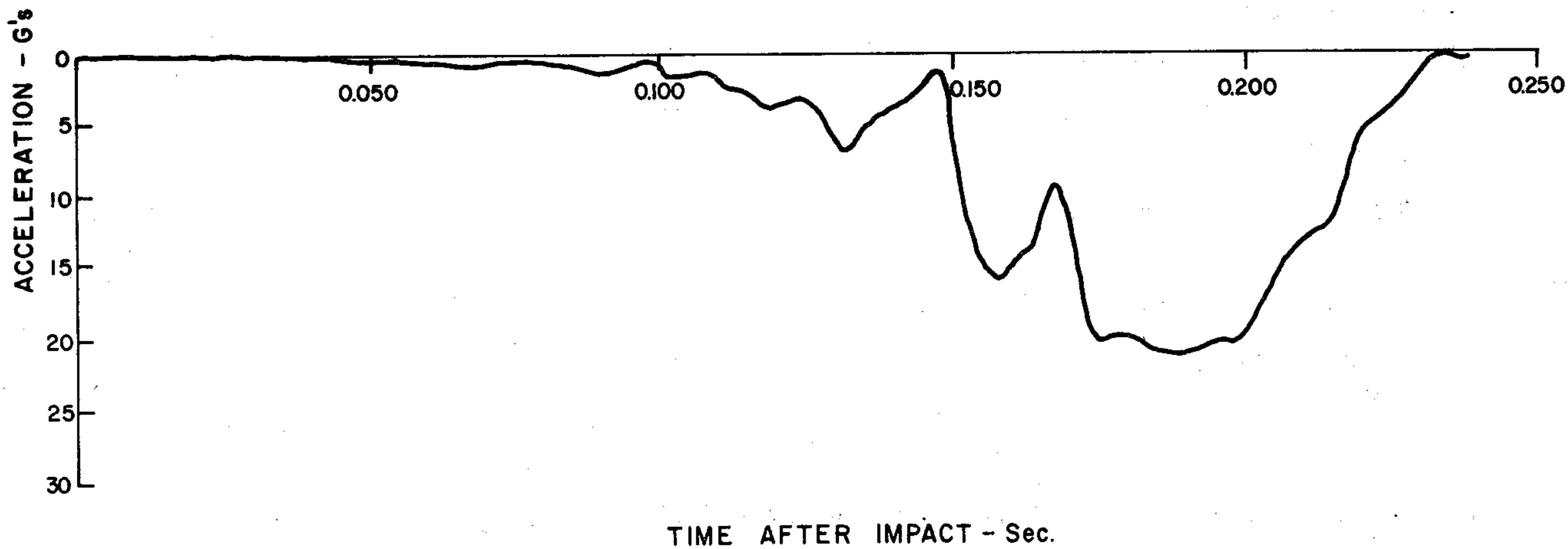


PLATE E-6

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH/ HEAD-ON /4690 lb. DODGE

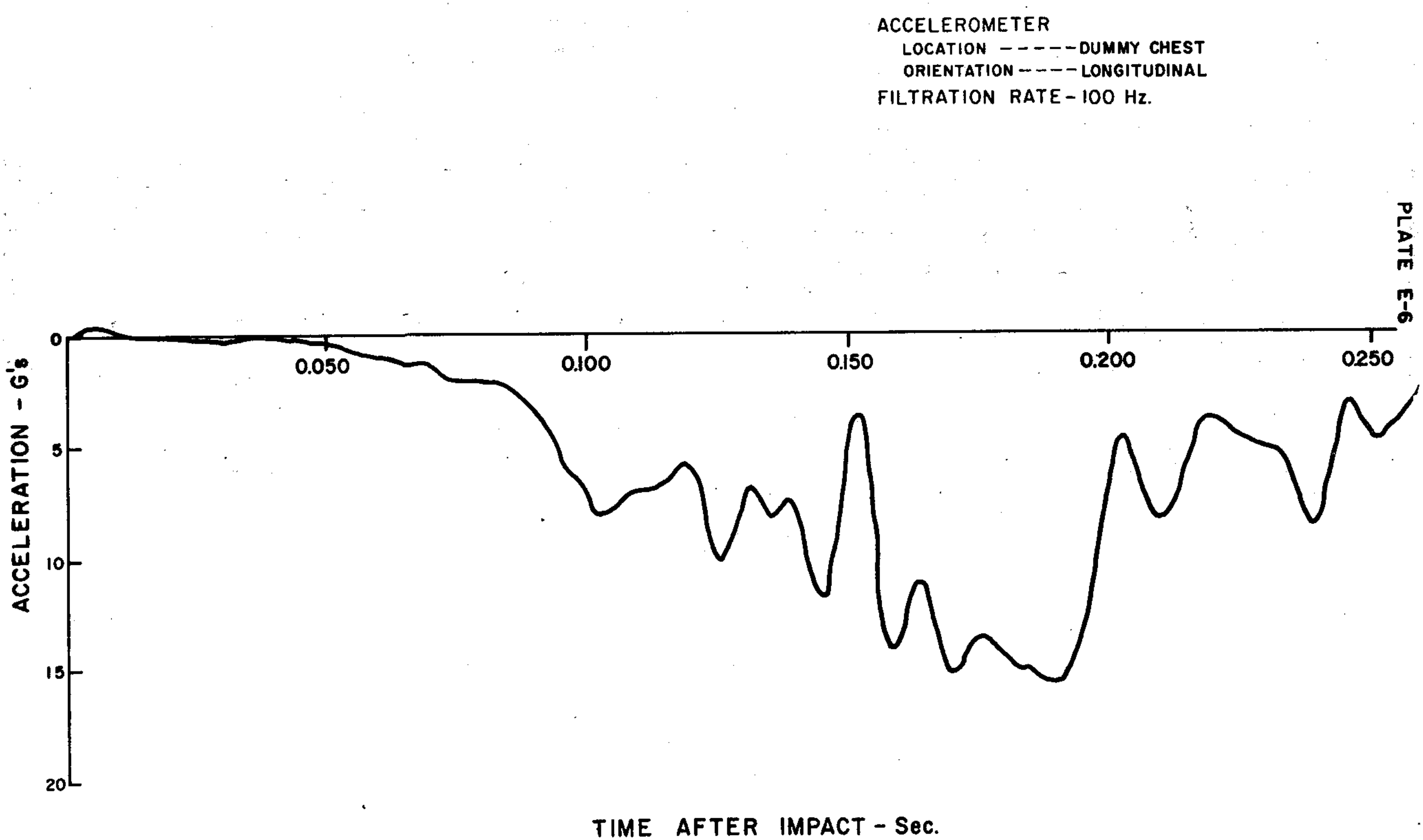


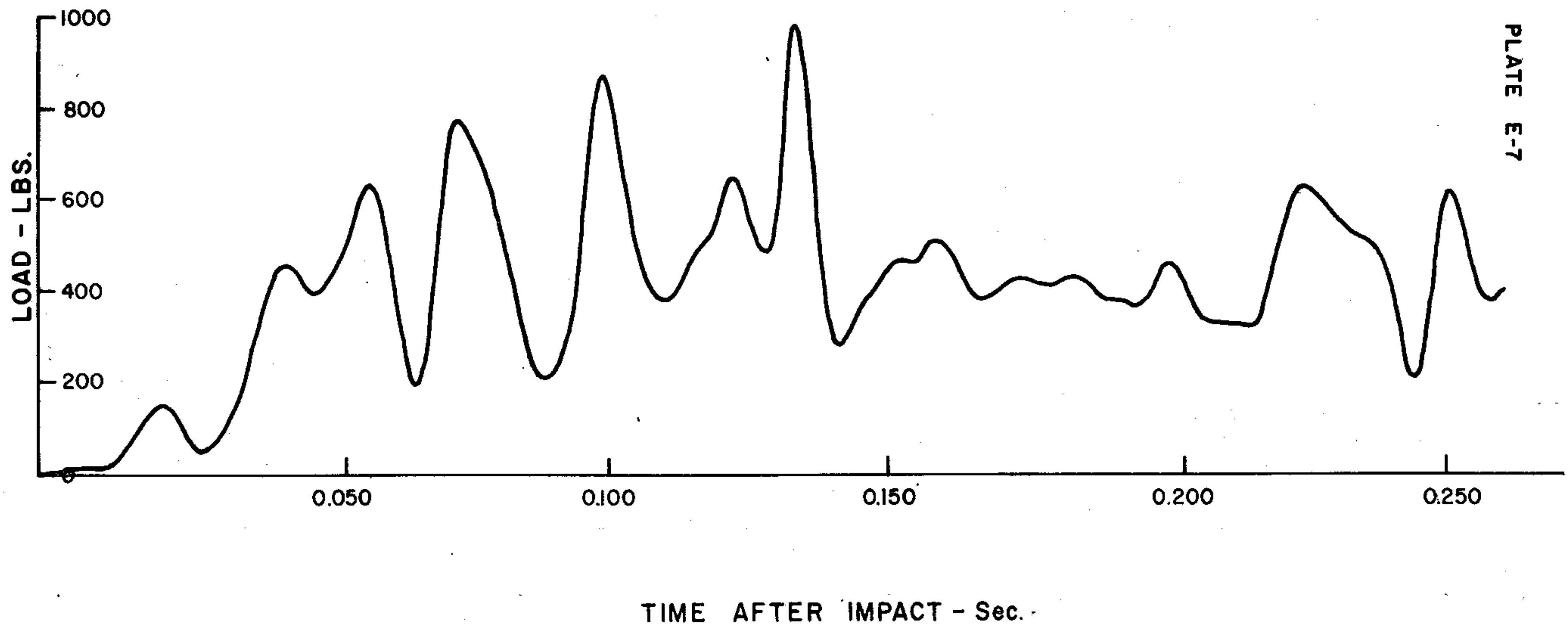
PLATE E-7

LOAD VS TIME

ENERGY ATTENUATOR - SAND TEST 241

58 MPH/ HEAD-ON / 4690 lb. DODGE

SEAT BELT TRANSDUCER
DUMMY'S LAP BELT
FILTRATION RATE - 100 Hz.



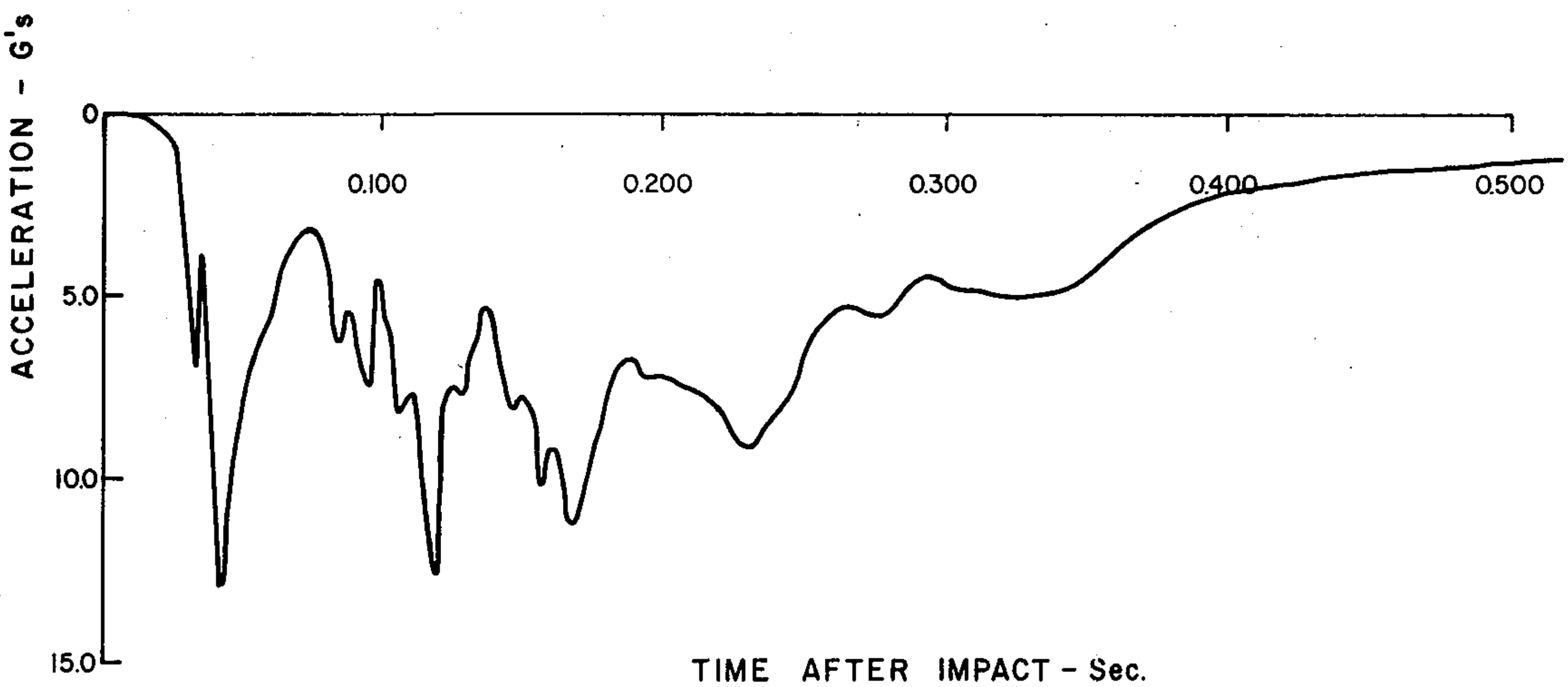
ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242

59 MPH / HEAD-ON / 1940 lb. VW

ACCELEROMETER
LOCATION ------ A* VEHICLE PASSENGER COMPART.
ORIENTATION ---- LONGITUDINAL
FILTRATION RATE - 176 Hz.

* SEE PAGE 8

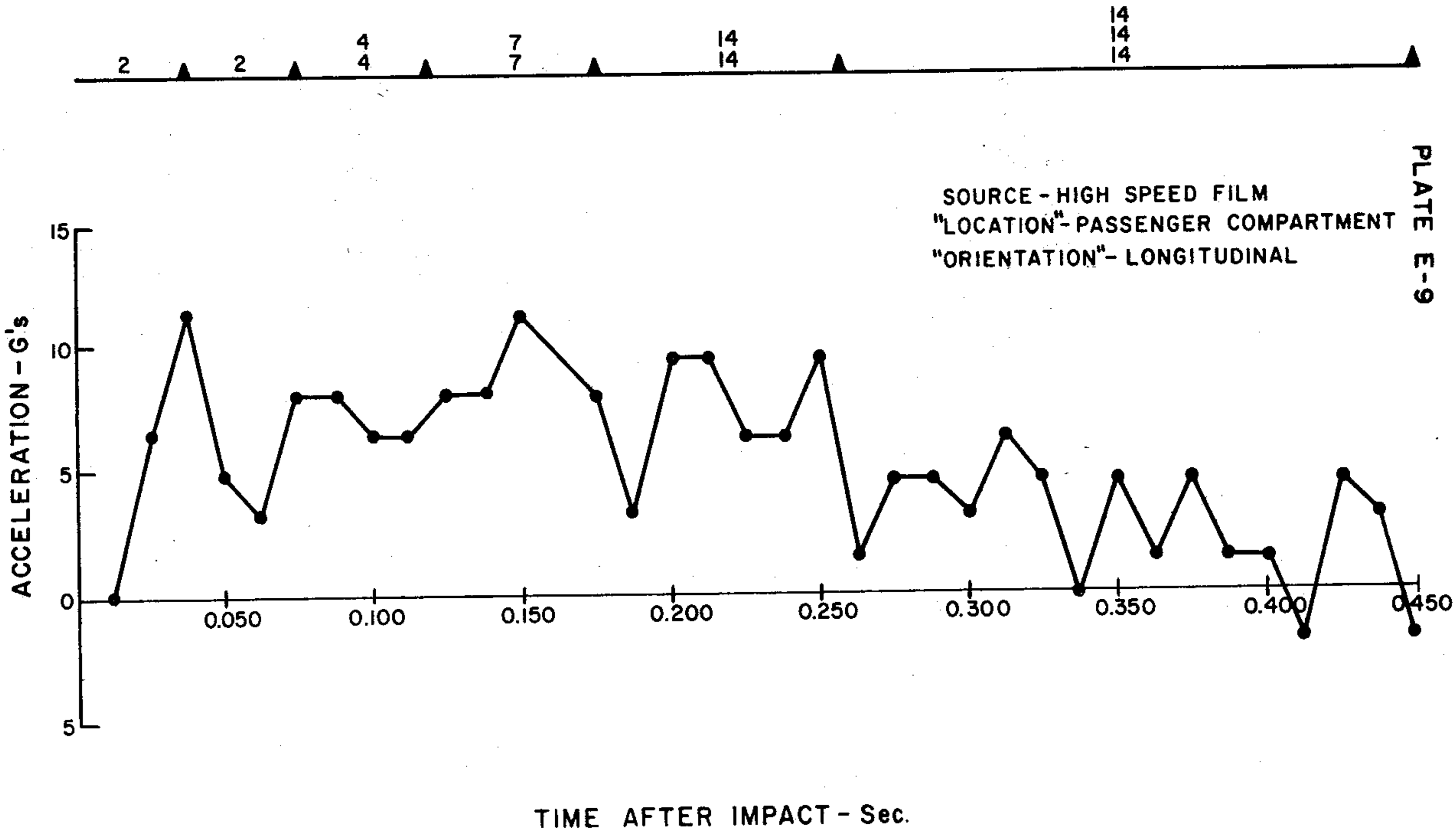


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242

59 MPH / HEAD - ON / 1940 LB. VW

LINEAR SCALES SHOW TIMES AT WHICH THE CRASH CAR PASSED THROUGH EACH THREE FOOT THICK ROW OF BARRELS. NUMBERS REPRESENT THE SIZE & NUMBER OF BARRELS IN EACH ROW.

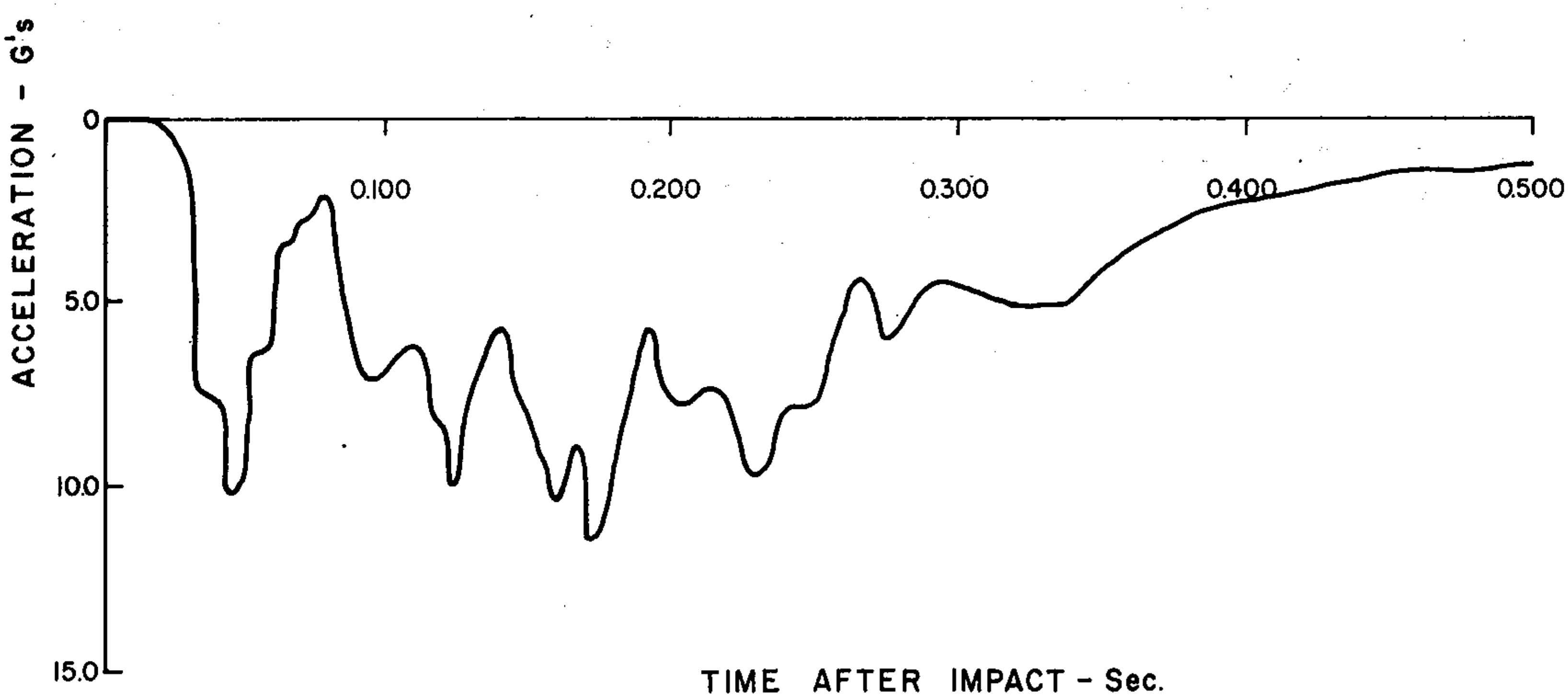


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242
59 MPH/ HEAD-ON / 1940 lb VW

ACCELEROMETER
LOCATION ------E* VEHICLE PASSENGER COMPART.
ORIENTATION ----LONGITUDINAL
FILTRATION RATE - 176 Hz.

* SEE PAGE 8



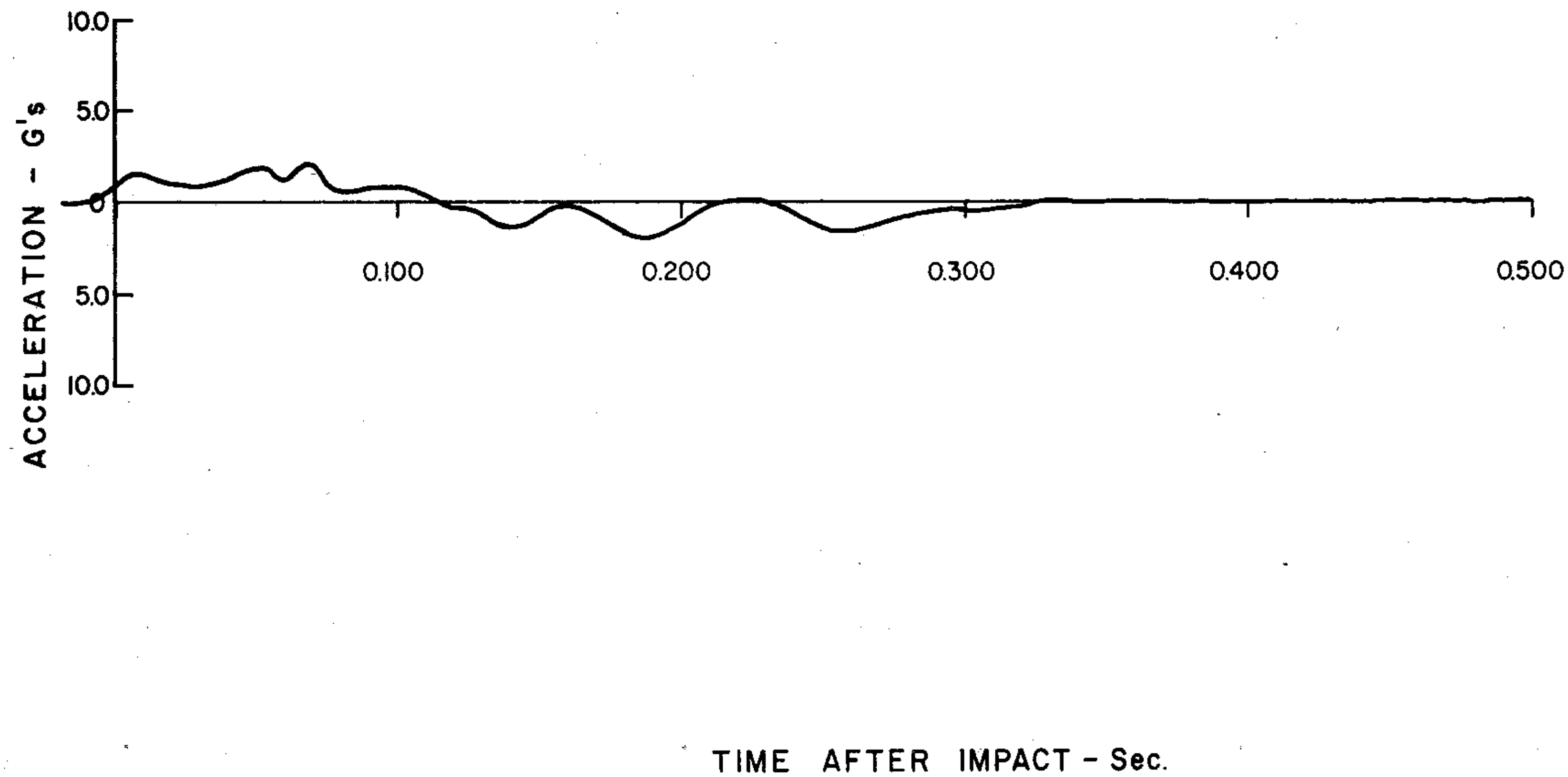
ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242

59 MPH/ HEAD-ON / 1940 lb. VW

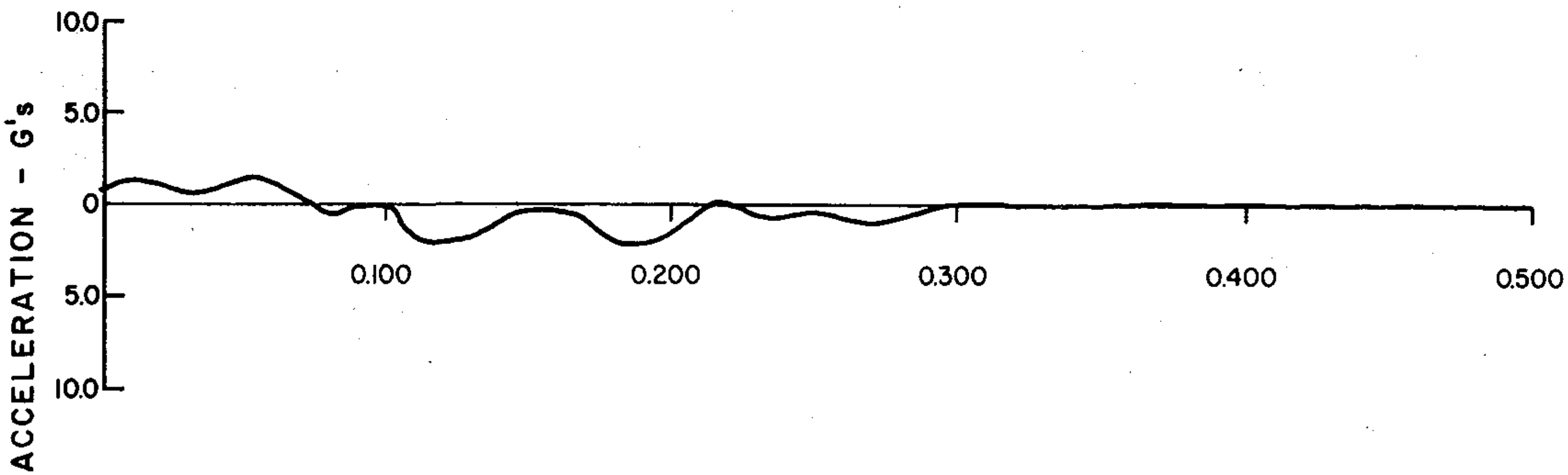
ACCELEROMETER
LOCATION ------A* VEHICLE PASSENGER COMPART.
ORIENTATION ----LATERAL
FILTRATION RATE-176 Hz.

*SEE PAGE 8



ACCELERATION VS TIME
ENERGY ATTENUATOR - SAND TEST 242
59 MPH/ HEAD-ON / 1940 lb. VW

ACCELEROMETER
LOCATION ------E* VEHICLE PASSENGER COMPART.
ORIENTATION ----LATERAL
FILTRATION RATE - 176 Hz.



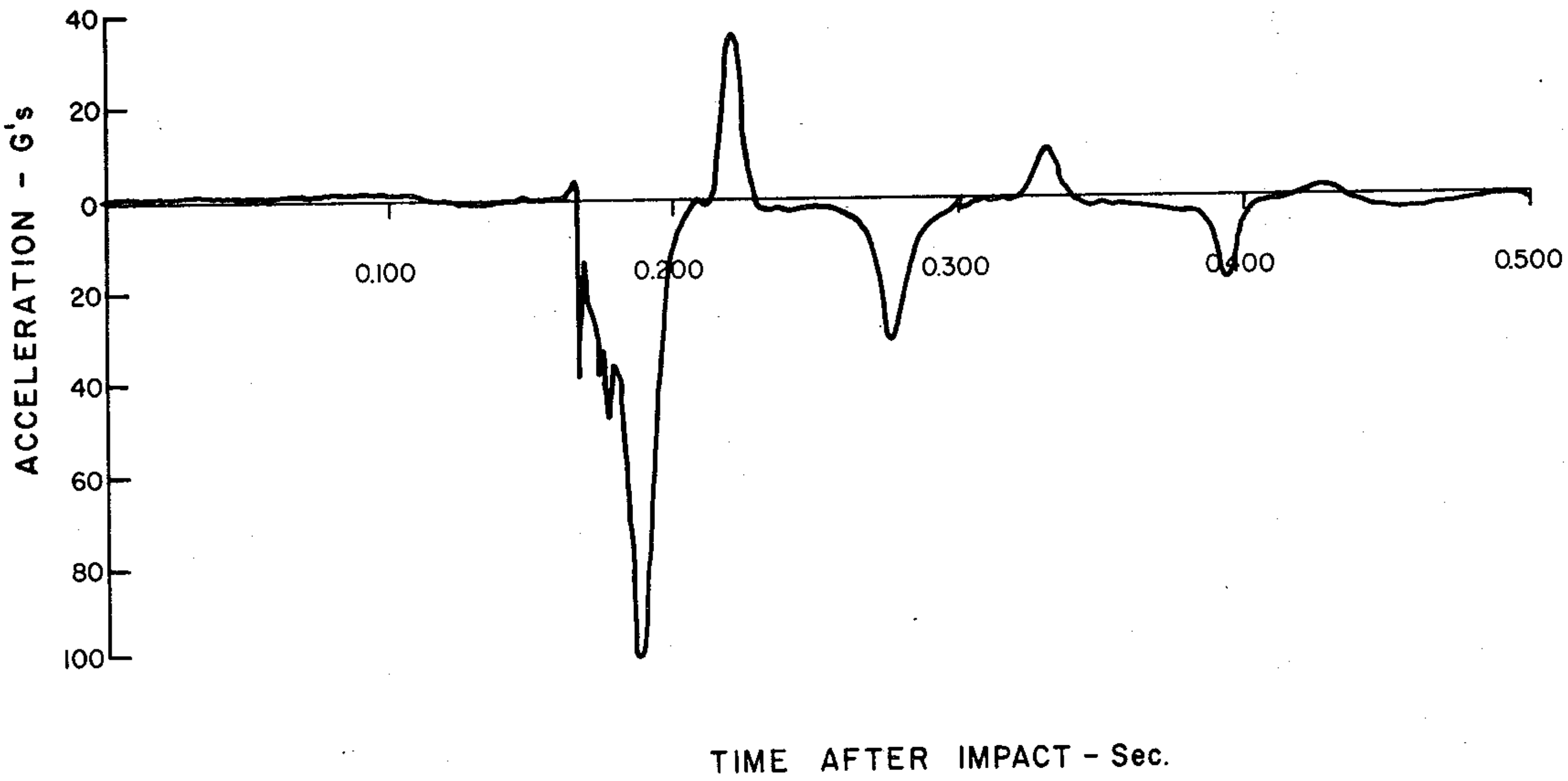
TIME AFTER IMPACT - Sec.

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242

59 MPH/ HEAD-ON / 1940 lb. VW

ACCELEROMETER
LOCATION ----- DUMMY'S HEAD
ORIENTATION ---- LONGITUDINAL
FILTRATION RATE - 176 Hz.

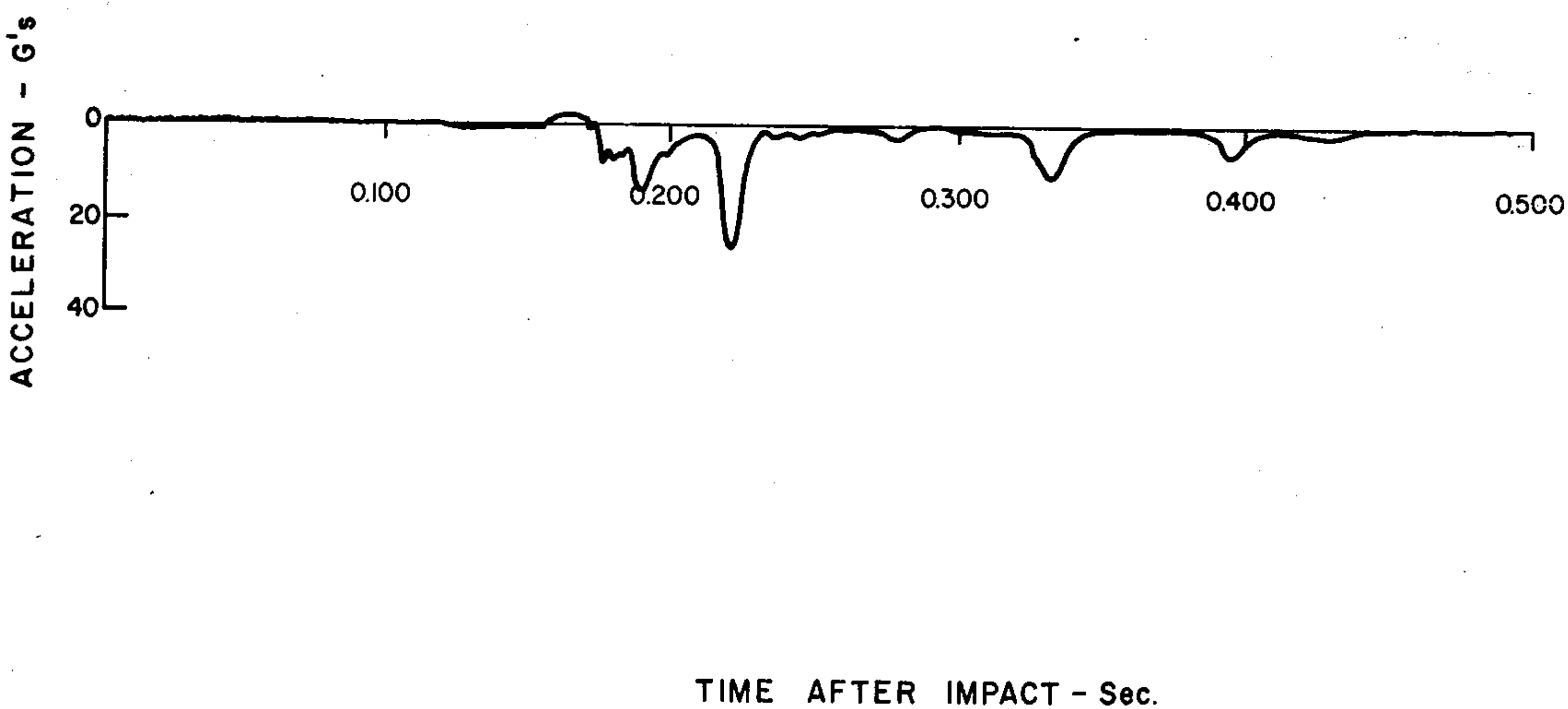


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND   TEST 242

59 MPH/ HEAD-ON / 1940 lb. VW

ACCELEROMETER
LOCATION ----- DUMMY'S HEAD
ORIENTATION ---- LATERAL
FILTRATION RATE - 176 Hz.

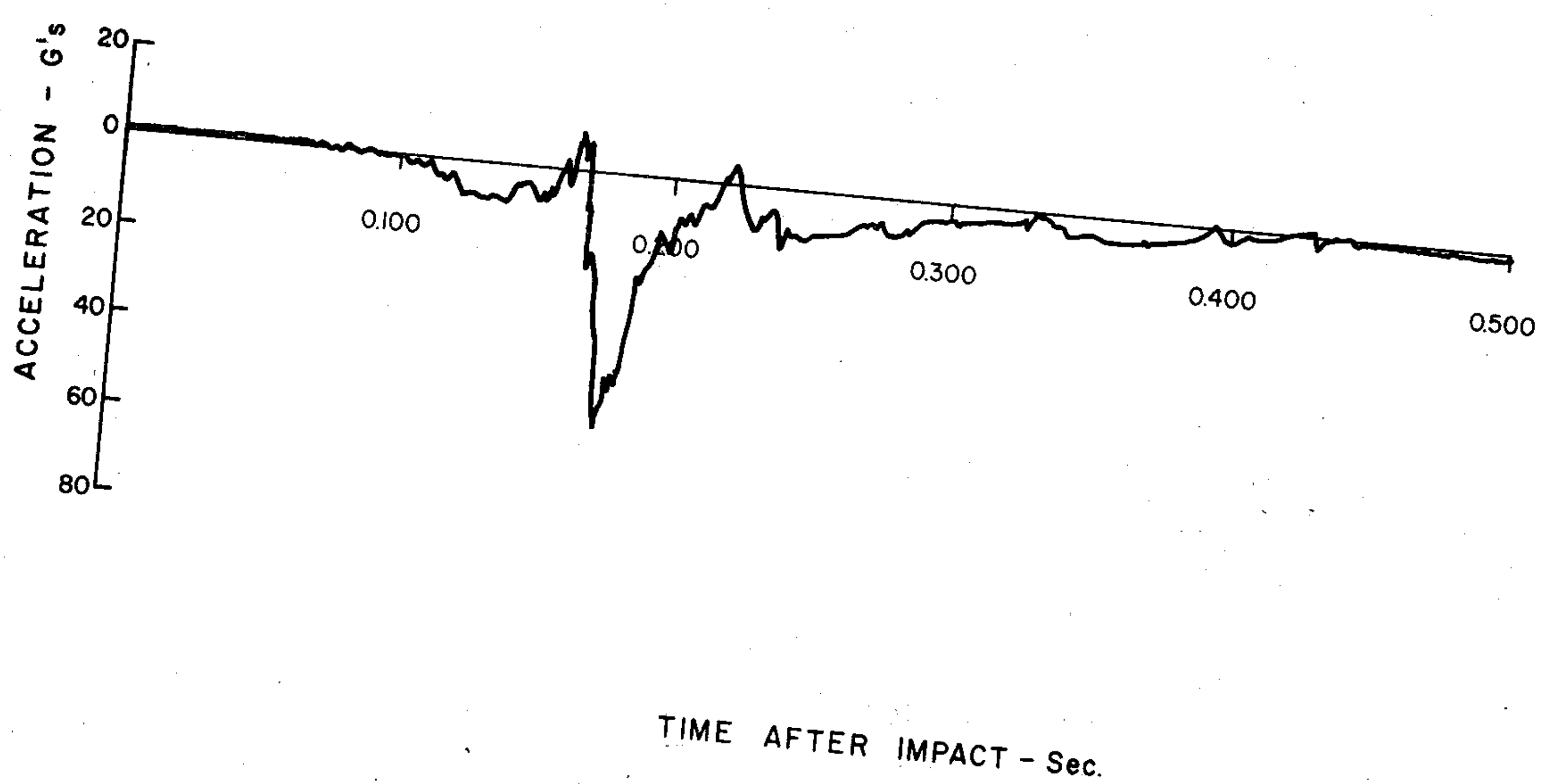


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242

59 MPH/ HEAD-ON / 1940 lb. VW

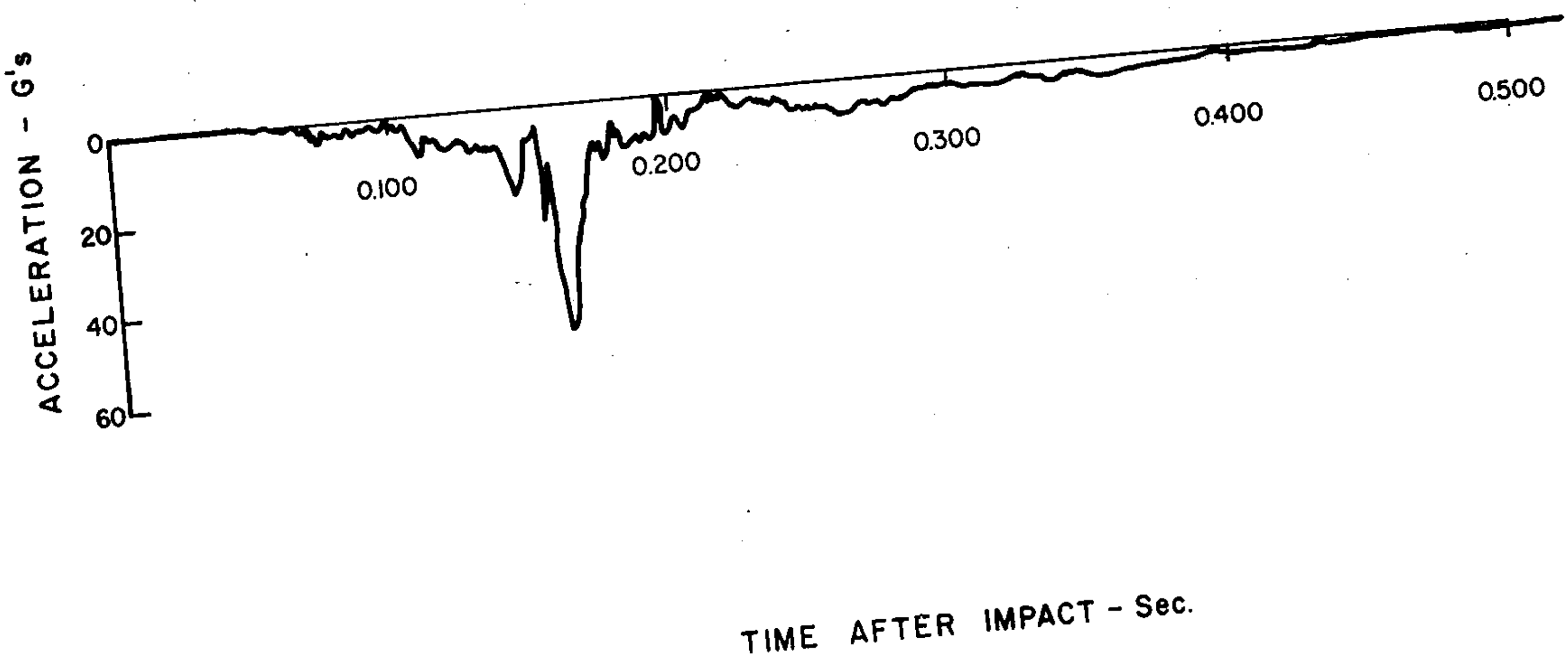
ACCELEROMETER
LOCATION ------ DUMMY'S HEAD
ORIENTATION ----- VERTICAL
FILTRATION RATE - 176 Hz.



ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 242
59 MPH/ HEAD-ON / 1940 lb. VW

ACCELEROMETER
LOCATION ------ DUMMY'S CHEST
ORIENTATION ----- LONGITUDINAL
FILTRATION RATE - 176 Hz.

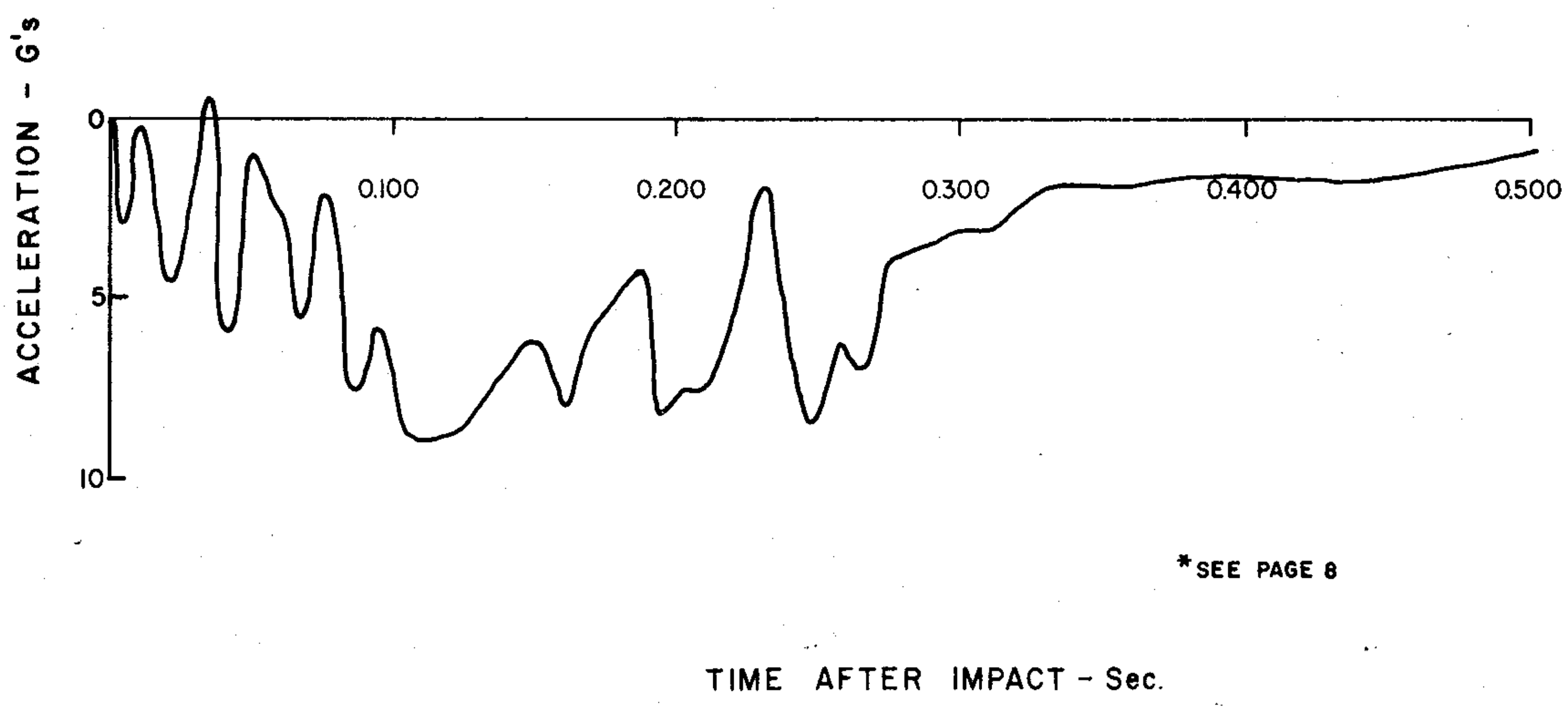


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243

57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION - - - A*- VEHICLE PASSENGER COMPART.
ORIENTATION - - - - LONGITUDINAL
FILTRATION RATE - 176 Hz.



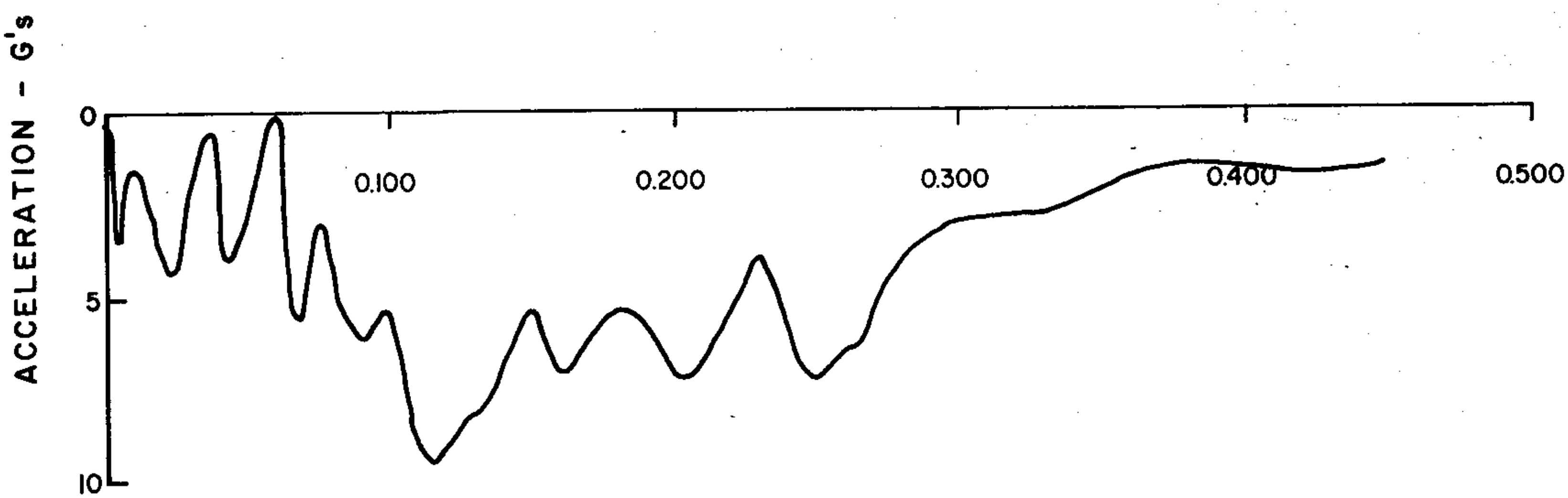
*SEE PAGE 8

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243

57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION ---E*-VEHICLE PASSENGER COMPART.
ORIENTATION----LONGITUDINAL.
FILTRATION RATE-176 Hz.



TIME AFTER IMPACT - Sec.

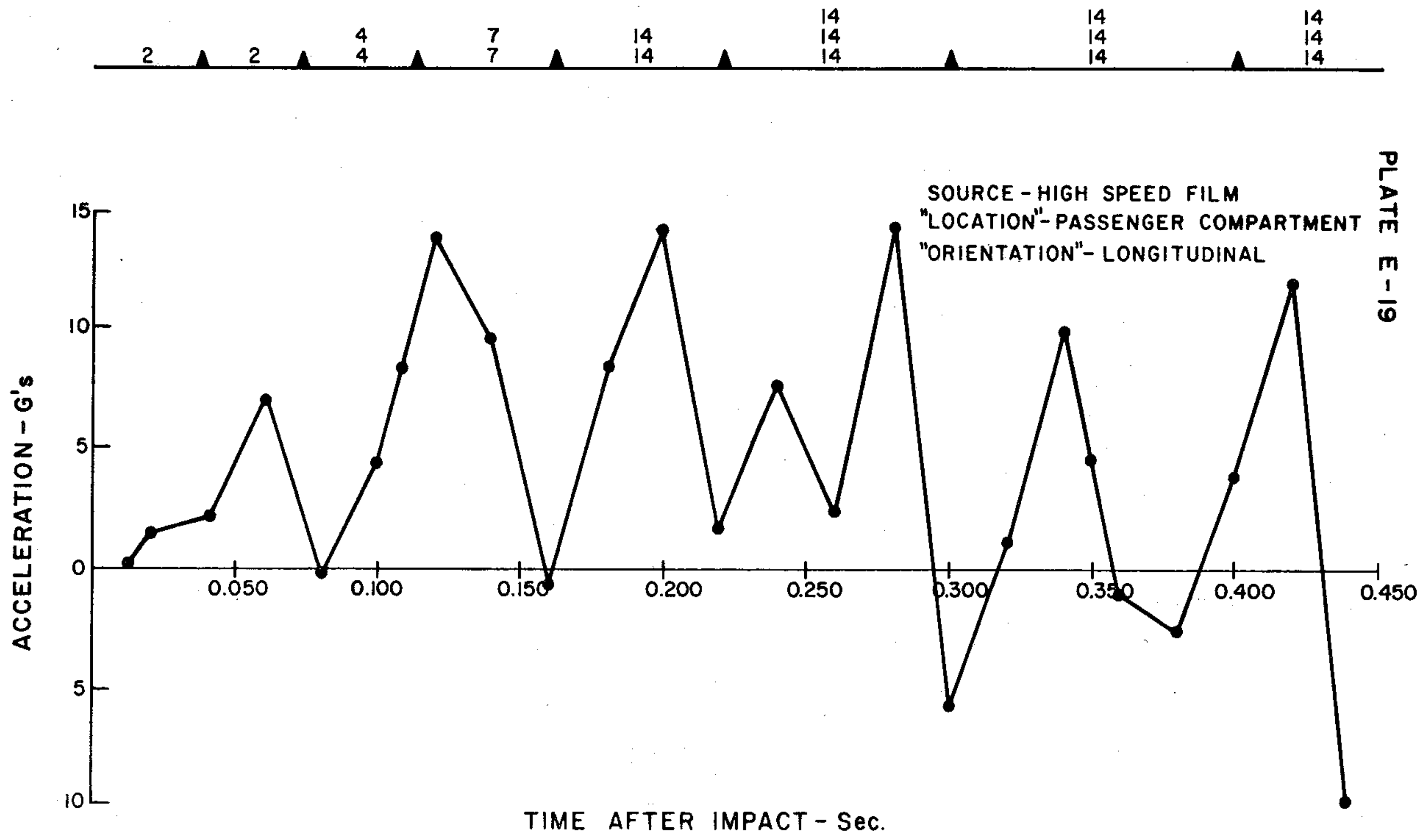
*SEE PAGE 8

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND   TEST 243

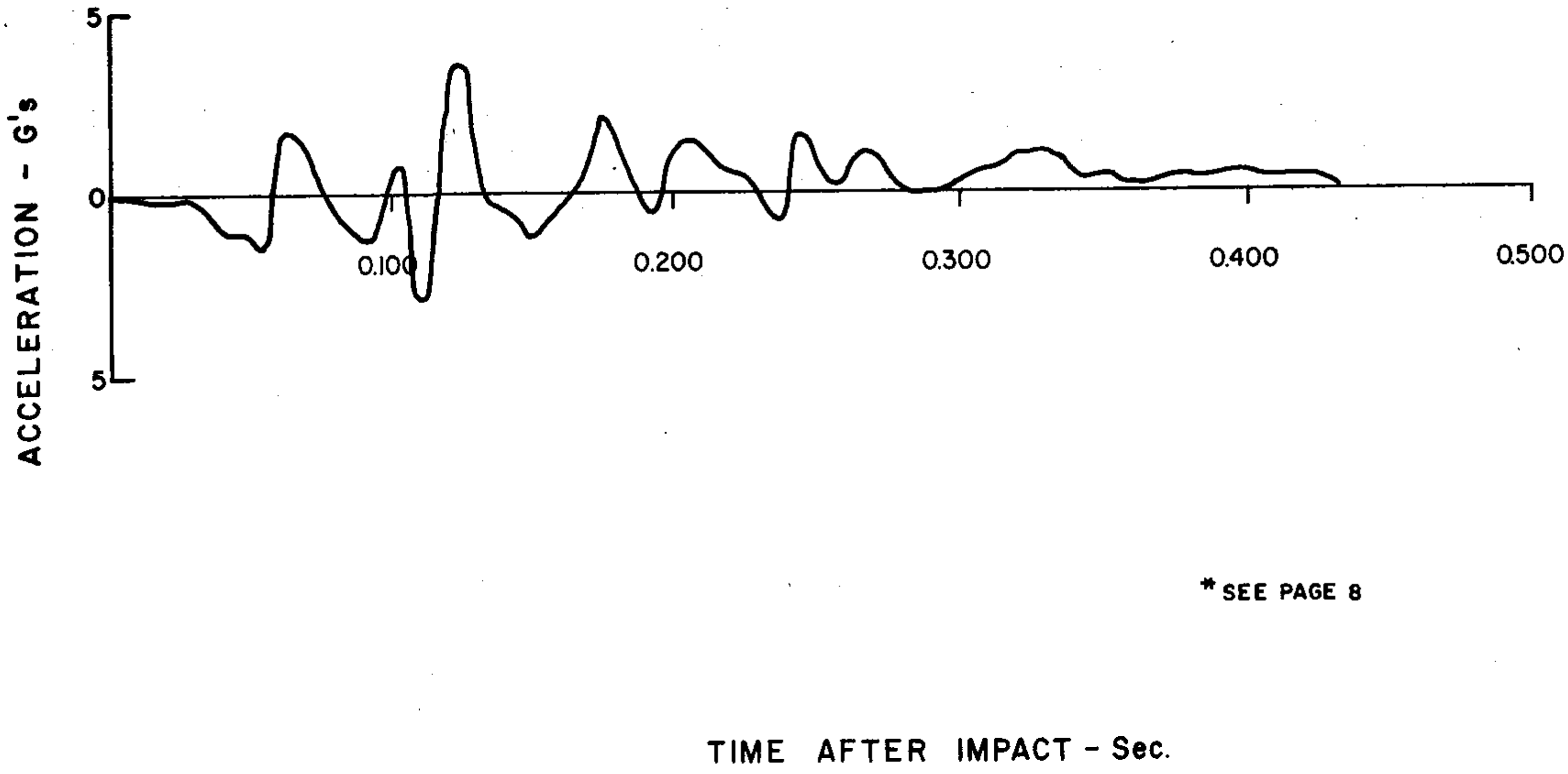
57 MPH / 15° AT NOSE / 4770 LB. DODGE

LINEAR SCALES SHOW TIMES AT WHICH THE CRASH CAR PASSED THROUGH EACH THREE FOOT THICK ROW OF BARRELS. NUMBERS REPRESENT THE SIZE & NUMBER OF BARRELS IN EACH ROW.



ACCELERATION VS TIME
ENERGY ATTENUATOR - SAND TEST 243
57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION - - - A*- VEHICLE PASSENGER COMPART.
ORIENTATION - - - - LATERAL.
FILTRATION RATE - 176 Hz.

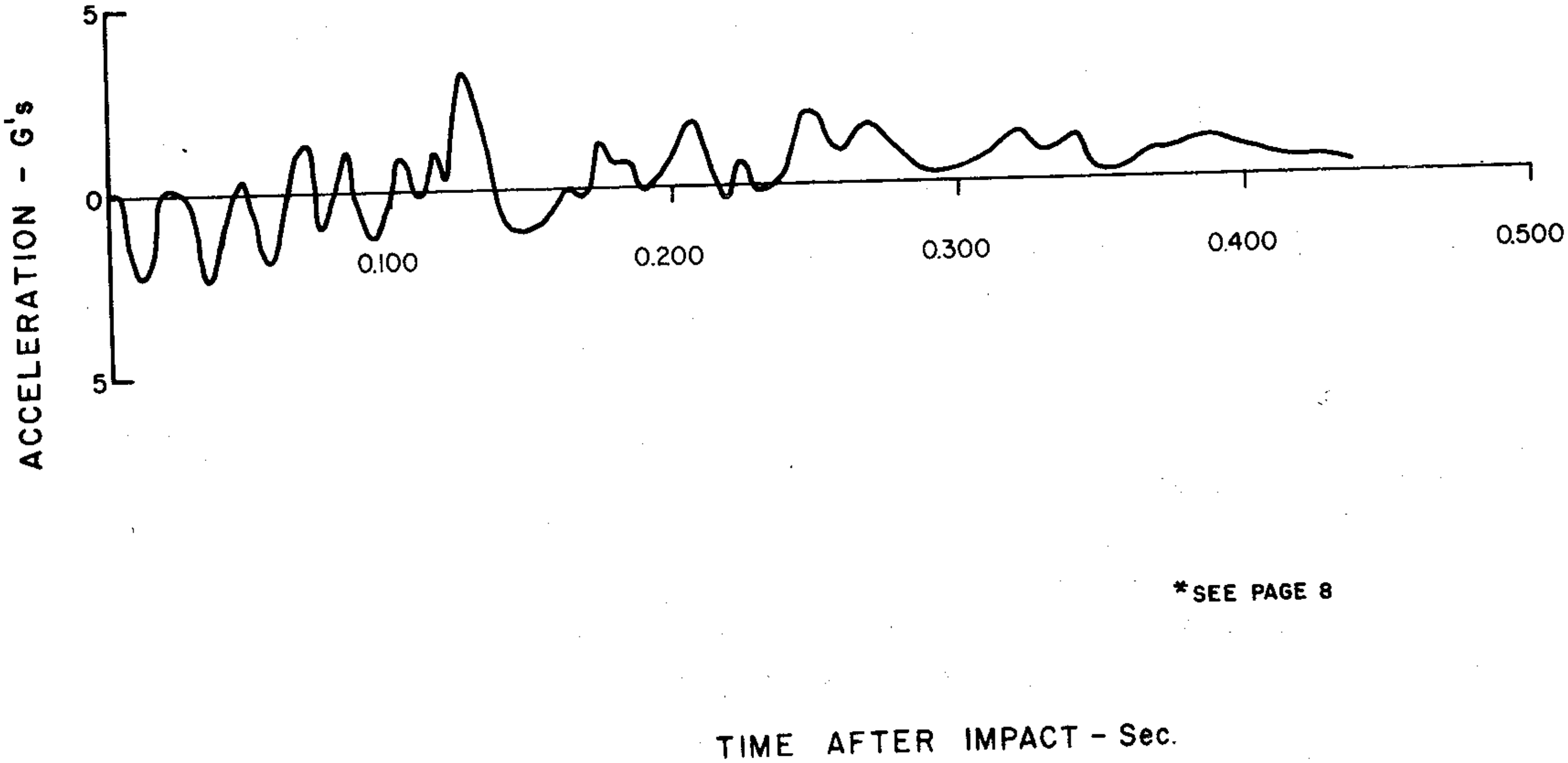


* SEE PAGE 8

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243
57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION ---E*- VEHICLE PASSENGER COMPART.
ORIENTATION ---- LATERAL
FILTRATION RATE-176 Hz.*



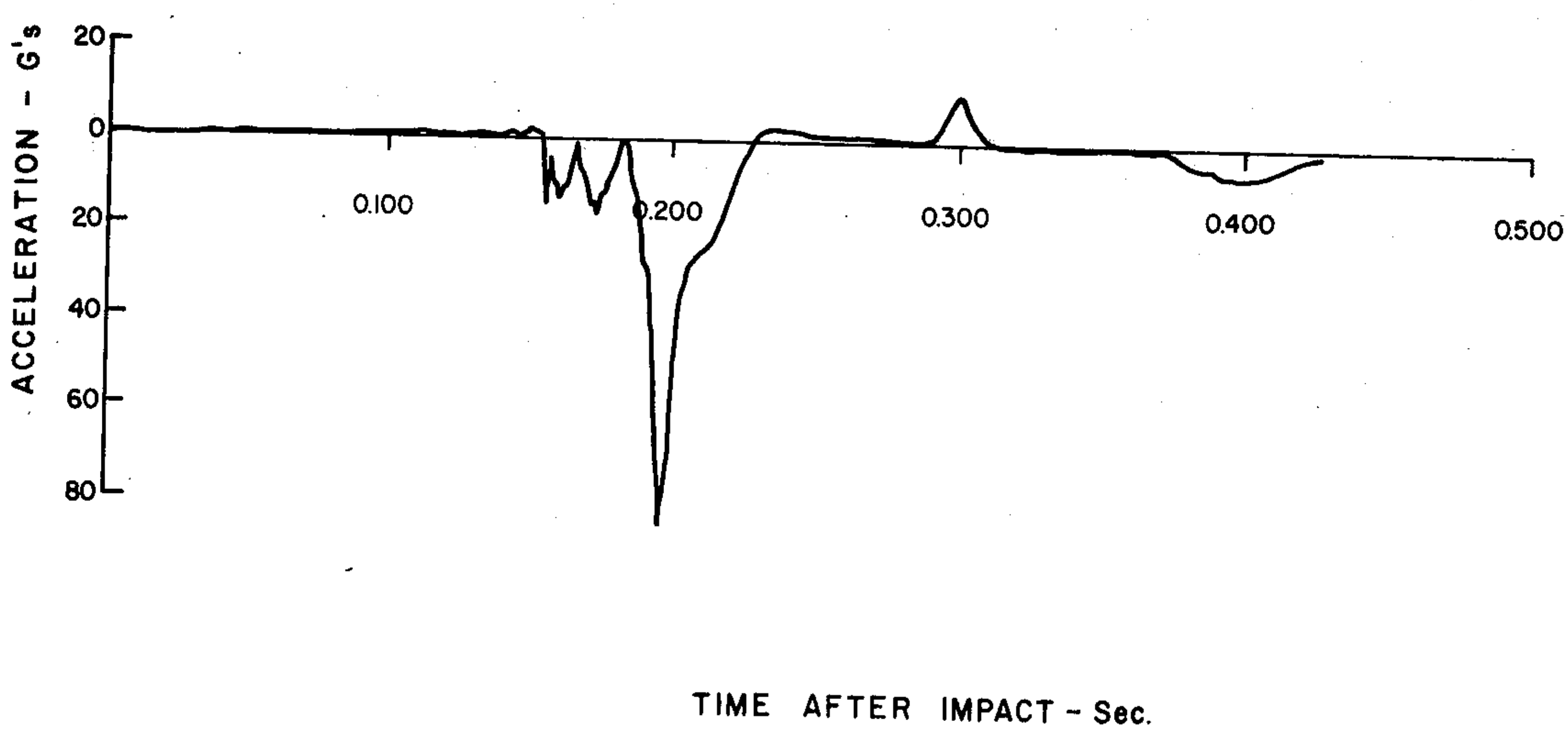
*SEE PAGE 8

ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243

57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION ------ DUMMYS HEAD
ORIENTATION ---- LONGITUDINAL
FILTRATION RATE - 176 Hz.

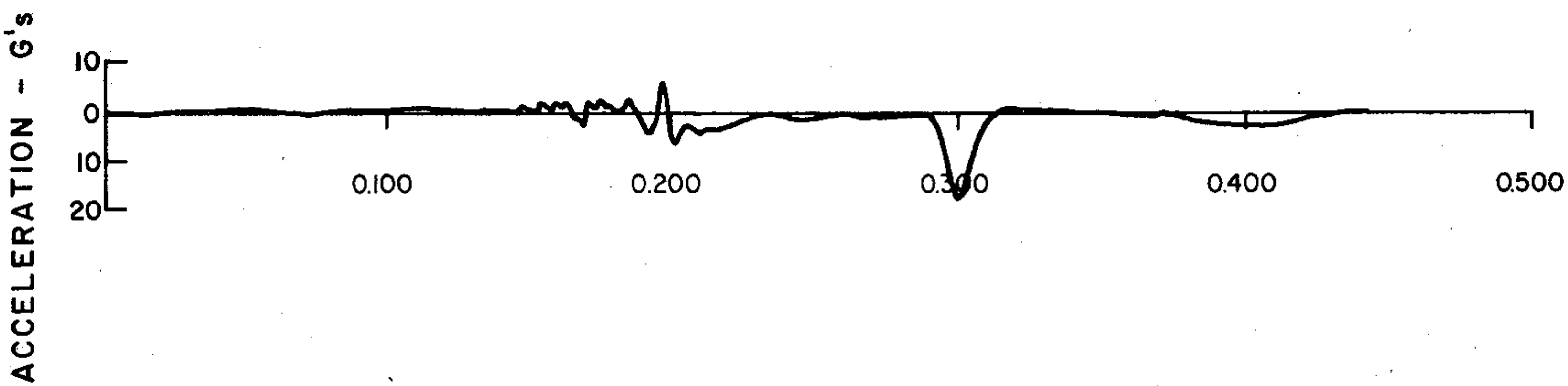


ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243

57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION -----DUMMYS HEAD
ORIENTATION ----LATERAL
FILTRATION RATE - 176 Hz.



ACCELERATION VS TIME

ENERGY ATTENUATOR - SAND TEST 243

57 MPH/15° AT NOSE/ 4770 lb. DODGE

ACCELEROMETER
LOCATION ------ DUMMYS HEAD
ORIENTATION ----- VERTICAL
FILTRATION RATE - 176 Hz.

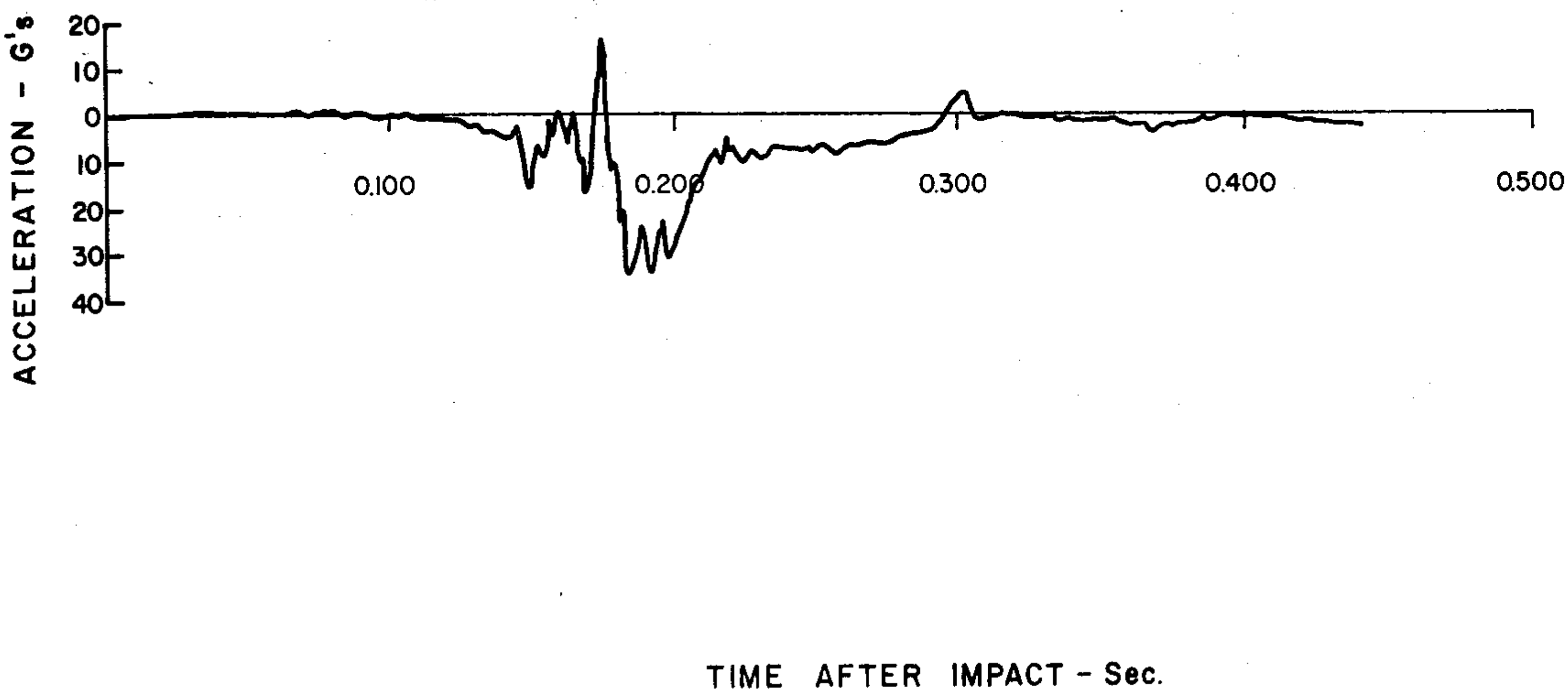


PLATE E-25

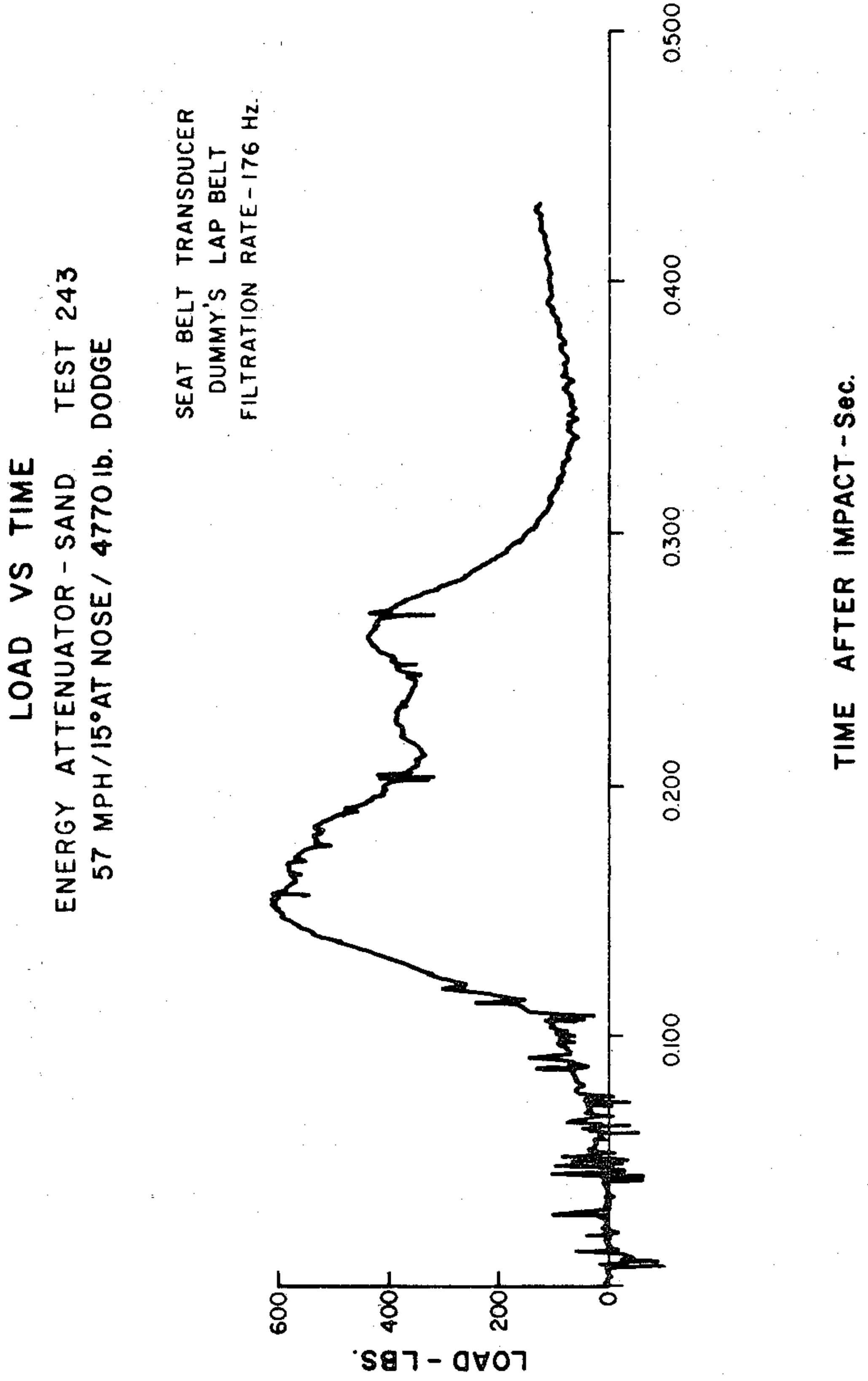

LOAD VS TIME
ENERGY ATTENUATOR - SAND TEST 243
57 MPH/15° AT NOSE/ 4770 lb. DODGE
SEAT BELT TRANSDUCER
DUMMY'S LAP BELT
FILTRATION RATE - 176 Hz.
LOAD - LBS.
600
400
200
0
0.100
0.200
0.300
0.400
0.500
TIME AFTER IMPACT - Sec.

PLATE E-26

IMPACTOGRAPH DATA

TEST 241

(58 MPH HEADON)

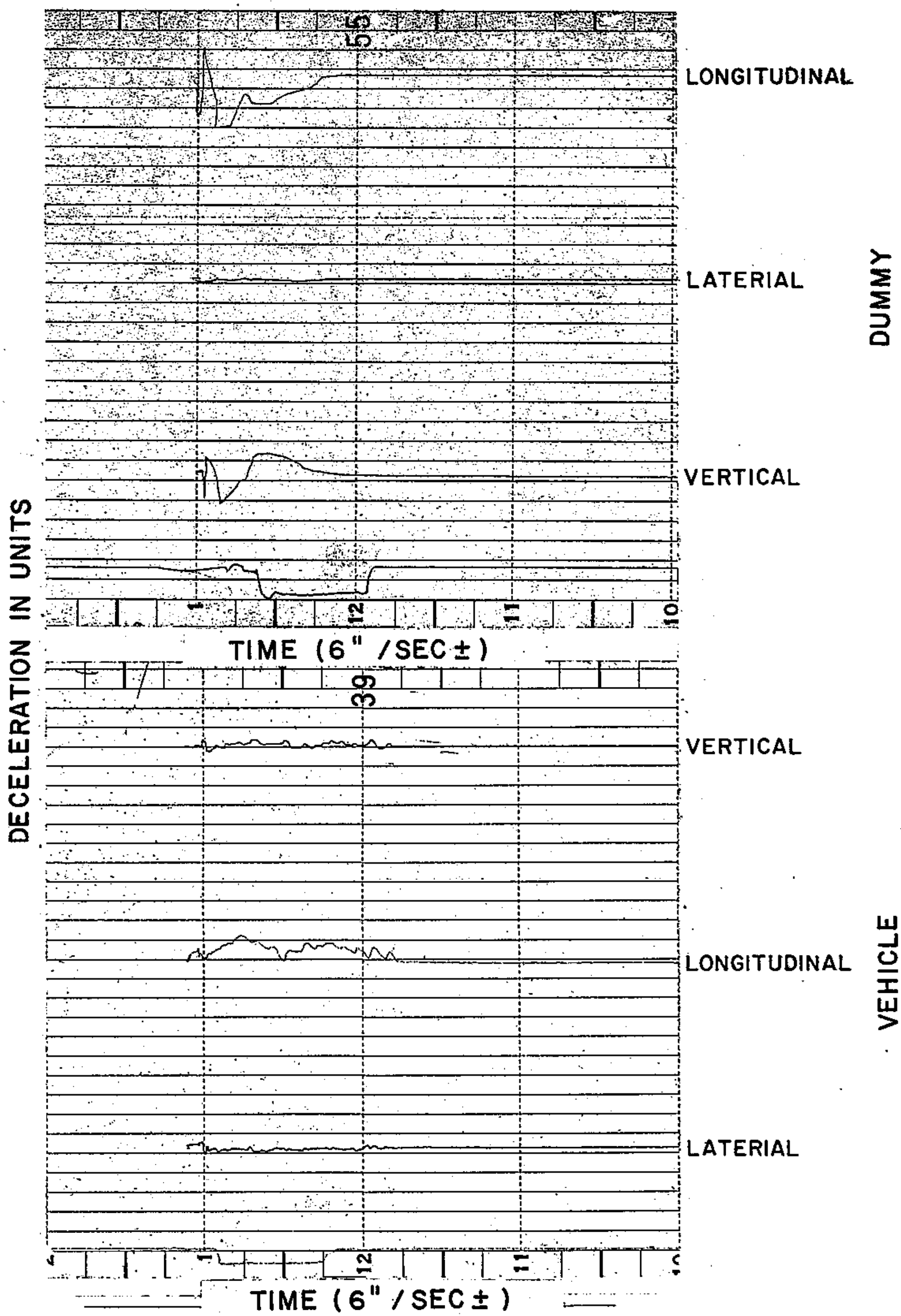
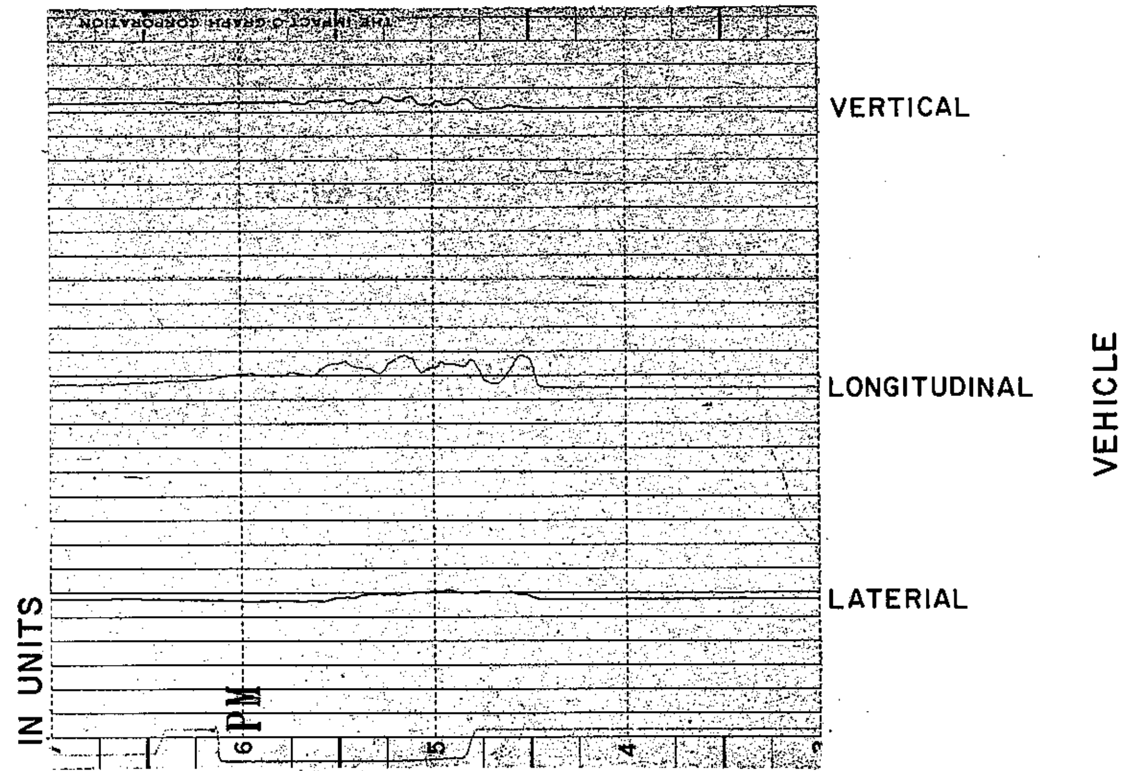


PLATE E-27
IMPACTOGRAPH DATA

TEST 242
(59 MPH
HEADON)



TEST 243
(57 MPH 15°
AT NOSE)